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A

RUDIMENTARY TREATISE

ON

GEOLOGY:

FOR THE USE OF BEGINNERS.

BY

LIEUT.-COLONEL PORTLOCK, R.E.

F.R.S., F.G.S., M.R.I.A., &c.

London:

JOHN WEALE,

ARCHITECTURAL LIBRARY, 59, HIGH HOLBORN.

M.DCCC.XLIX.

HUGHES AND ROBINSON, PRINTERS,
KING'S HEAD COURT, GOUGH SQUARE.

PREFACE.

This sketch of a Science, at once distinguished by philosophic interest and by practical importance, I offer as my humble contribution towards the completion of a design which has in part originated in the suggestions of my friend Lieut.-Colonel Reid, Royal Engineers, late Governor of Barbadoes.

Feeling a warm attachment for my profession, and desiring to see it advance in public estimation, I value and respect any of its members who, like Lieut.-Colonel Reid, R.E., and Lieut.-Colonel Sabine, R.A., have endeavoured to combine military eminence with scientific attainments; and I trust that it will be ere long acknowledged by every one that a Scientific Corps like the Royal Engineers must rest its claims for public support as well on scientific as on military excellence.

To every Military as well as Civil Engineer a knowledge of the Natural Sciences is indispensable; and I shall only add, in reference both to the professional and to the general reader, that my aim in this Treatise is only to set before them the leading principles of Geology, and to kindle in their minds a

desire to advance further in its study by a perusal of the works of Lyell, Ansted, Mantel, Phillips, De la Beche, Buckland, Sedgwick, Murchison, Forbes, Owen, and many others, who have succeeded in placing English Geologists in the first rank amongst the living Students of Nature.

J. E. Portlock.

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RUDIMENTARY GEOLOGY.

CHAPTER I.

INTRODUCTION.—*Experience* or *Practice* and *Theory* must be combined for the successful progress of all Science, and for the perfect development of Art.

As it is hoped that this little book may be read by many members of that valuable class of persons who are called practical men, it seems desirable to set before them such reasons as may dispel the prejudice, not unusual on their part, against the men called scientific, and at the same time justify their claim to that proper station in the estimation of men of science, which, as their most powerful auxiliaries, they ought to hold. The mutual distrust between scientific and practical men, though decreasing, does still frequently exist, and is to be ascribed, as in most human differences, to the misapprehension or misinterpretation of a term, which term is in this case 'Science.' What then does the term Science actually signify?—simply Knowledge: but it may be viewed in two different lights, and be understood as implying either

A Knowledge of Facts, the result of observation; or,

A Knowledge of Laws, the result principally of combining and reasoning upon facts.

If these divisions be kept in view, it becomes evident that every human being must make more or less progress in the first branch of knowledge, as it is impossible to live and not to acquire some experience of facts; but that few, in comparison, enter upon the second, which requires, in addition to observa-

tion, a power and habit of reflection. And yet it must not be supposed that an exercise of the higher quality of reasoning can dispense with that of observation, as every such attempt has only led to mysticism, and retarded the progress of that real knowledge which in every case proceeds either directly or indirectly from observed facts.

When the comparison of observed facts has led to the discovery of a law or rule according to which those facts are in connection one with the other, the mind acquires a power of extending or developing that law beyond the limits of the observed facts, and thus is enabled to advance into new regions of inquiry, and to foretell facts which have yet to be observed. And in like manner, the law or rule which has been ascertained to connect together one set of facts, may be found to agree with or even depend upon a law which connects together another set, the more compound law being thus traced up to the simple; and in many cases laws which from the difference in the nature of the observed facts have been deemed independent of each other, are brought into connection by being referred to some more simple law of which they are all found to be developments.

Professor Lloyd ('Lectures on the Wave Theory of Light') has illustrated this subject. "You are aware," he says, "that in one mode of studying that interesting science, Astronomy, the laws of Kepler are assumed as fundamental principles, and from them, when unfolded, all the more obvious appearances of the planetary system are deduced. In Physical Astronomy, on the other hand, the laws of Kepler themselves are derived as *consequences of a primordial law of matter*, and the development of this higher principle has brought to light a multitude of other laws of the universe, which mere observation could have never reached." The example of Kepler is most instructive, as he may be viewed in the light of a practical man, submitting his prejudices to the test of experiment, and, by diligently observing the movements of the planet Mars, and patiently comparing together its ob-

served places, acquiring evidence that the orbit or curve in which it moved round the sun, was not a circle but an ellipse, the sun being in one of its foci. This law of elliptic motion, and Kepler's two other laws, having been generalized and proved to depend on the elementary laws of matter, the range of observation was expanded until the whole material universe had, as it were, been spanned by the Intellect of Man; and when, from the independent study of the motion of each planetary body, the Astronomer turned to the still more difficult investigation of the mutual action of one upon the other, and finally overcame and reduced to order all its difficulties, the Theoretic Astronomer was enabled, in the persons of Messrs. Adams and Le Verrier, to advance before the observer, and to direct him where to look for that remote, and until then undiscovered planet, the existence of which they had inferred, by calculation, from its perturbating effects on other planets. This noble result of a long course of patient practical observation, followed up and methodized by intense study and reflection, can scarcely be equalled in the annals of the human mind; and yet it is not the only one supplied by even this one science.

Light is, as a fact, familiar to every one, however conflicting may be the modes of explaining the laws by which it acts. To our senses it appears, as seen in the flash of a gun, instantaneous, and yet it is progressive. This fact of the progressive movement of light was discovered by Roemer, when, observing as a practical man the eclipses of Jupiter's satellites, he found that the mean time of the emersion of a satellite from the shadow of Jupiter's body was greater or less according as the distance of the earth was greater or less than its mean distance from Jupiter, such difference being due to the different times occupied by light in passing through the respective distances.

By a number of comparisons of the times of the emersions of Jupiter's satellites in the varying positions of the earth, it was ascertained that the reflected light occupied about 16′ 26″

in traversing the earth's orbit, and it may be stated generally in numbers that the velocity of light is about equal to 200,000 miles per second, or more precisely 166,072 geographical miles, a velocity almost a million times greater than that of sound. Such a velocity seems beyond human comprehension; and yet the Astronomer, still pursuing the practical course of observation, has succeeded in measuring distances so vast that they permit the velocity of light to be used as an element in their expression. It is thus that the light of some of the fixed stars, whose distances have been determined, must have taken 3, 9¼, and 12 years to travel to the earth; or supposing the whole universe contemporaneously created, 3, 9¼, and 12 years must have elapsed before those stars respectively could have been perceived on the earth; and were they now to be annihilated, the same periods must elapse before they will cease to be visible. There may be heavenly bodies the light of which has not yet arrived at our terrestrial surface, and others may have passed away, although yet apparently shining upon us. The elder Herschel even thought that the light of the most distant nebulæ discovered by his 40-foot refractor had required two millions of years to reach our eyes; and we may therefore well say with Humboldt, that "whilst we penetrate with our large telescopes at once into space and time, and measure the one by the other, we may receive the rays of light which come to us as if they were voices telling of the past; and however much we may diminish both the supposed distance whence the faint light of the nebulæ or the barely discernible glimmer of the remotest cluster of stars reaches us,—and the thousands of years which serve as the measure of that distance,—it will still remain true that, according to the knowledge which we possess of the velocity of light, it is more than probable that the light of the most distant cosmical bodies offers us the oldest sensible evidence of the existence of matter." And is not this a most important testimony for the Geologist; for when he too is obliged to speak of vast periods of time, may he not appeal to the Astronomer for proof, that the first act of

creative power was exercised at an epoch so remote, that even the mighty velocity of light, and the vast distances of the celestial bodies, have as yet failed as measures to determine it?

The other phenomena of light, as its refraction, its double refraction, and its polarization,—by which terms are expressed those very remarkable effects produced on light in its passage through crystalline bodies, and which have become indicative of the internal constitution of such bodies,—might be also adduced in illustration of the results of a happy union of the practical and theoretical, or in other words, the observing and reasoning systems. It is indeed by the knowledge first acquired by induction from facts observed, and to the mechanical skill applied in aid of it, that the refracting telescope, and by a similar knowledge of the laws of reflection of light, the reflecting telescope, have been so perfected as to open to our view an infinity of worlds, and to enable us almost to discern the steps of their creation, whilst the achromatic microscope has been made to reveal to our gaze an infinity equally wonderful, though it is that of minuteness, and to teach us the wonderful truth, that some of the solid rocks of our world are but an accumulation of countless myriads of minute organic bodies. Such intellectual triumphs as these demand on our part a tribute of admiration, not merely to the exalted genius which seizes on the laws which connect together great physical phenomena, but to the practical man, that is, to the patient, careful, and acute observer, who diligently watches for facts, and subsequently submits the theory established on them to the test of experiment.

Let another example be taken from Astronomy: compare the ancient Mariner whilst cautiously pursuing his track along the shore and watching the declining star,—for he too had observed that the movements of the celestial bodies were regular, not arbitrary,—with the skilful voyager of the present time, who boldly quits the land, and securely steers his course over the expanse of ocean. To him also, the heavens afford a guiding light for his adventurous progress; but it is no

longer a mere glimmering, as an accurate knowledge of the distances and movements of the various heavenly bodies has enabled the Astronomer to supply the Mariner with tables and formulæ for determining from celestial observations his exact position, and he now moves as securely upon ocean as upon land. And even upon the land, where the dense forest clothes the surface and forbids the ordinary operations of the Surveyor, recourse can be had to celestial observations, as was recently done in the determination of our North-Eastern American boundary, when the Surveyors, Officers of the Corps of Royal Engineers, having first determined the latitudes and longitudes of the ends of a line of 60 miles, deduced the azimuth or bearing of each end from the other, and then proceeded to cut down the trees according to these bearings, beginning simultaneously at each end, and so pursuing the respective lines through the forest until they both nearly met, the two parties emerging not indeed exactly opposite to, but in close proximity to, each other.

It is thus that Astronomy, both in its marine and its terrestrial applications, affords the most powerful proofs of the advantage of never separating practice from theory; of considering the observer, who is the practical Astronomer, as the fellow-labourer of the Theorist, and at the same time of frankly acknowledging the benefits derived from the profound investigations of the latter. M. Biot has thus stated the only safe method of arriving at knowledge, namely, that by induction. "When observations have accumulated, they are compared together, and their errors discovered and eliminated. A correct knowledge is thus acquired of the state of the heavens, as to what is constant and what is variable, whether it be in a day, in a year, or in some still greater interval of time. The task of observing, or Practical Astronomy, has now ceased, and that of Theoretic Astronomy commences. Similar phenomena are now compared together, in order to discover the laws by which they are linked together; and then again the inquiry is extended until the movements of the heavenly bodies have been shown to be in harmony with those

mechanical forces and those laws of attraction which are found to operate upon all material bodies."

Chemistry is replete with illustrations of the principle which these observations are intended to inculcate: it is an experimental science in the highest degree, and at every step of its progress appeals for information to the crucible and balance. And yet, though a practical science, it is rich in deductions of the highest philosophical interest which spring from the exercise of powerful reasoning upon carefully observed facts. Thousands had observed the phenomena of bodies falling to the ground ere they were destined to suggest to the mind of a philosopher the laws of universal gravitation; and, in like manner, many a patient Chemist had weighed the resulting constituents of his careful analyses, ere the mind of Higgins obtained a glimpse, and that of Dalton a clear perception, of the remarkable law of definite proportions, by the knowledge of which Chemistry was at once raised to the rank of the exact sciences. This law has now become so familiar that its beauty and grandeur are less considered than its convenience; but it may be fairly doubted if in the whole range of sciences any greater discovery was ever made than that which established the fact, that the combinations of material substances are neither arbitrary in kind nor quantity, but fixed by a definite and invariable law as regards each individual substance. The atomic theory of Dalton is a philosophic or theoretic expression of this law; but whatever may be the fate of the theory, the law itself will remain incontrovertible, nor ought the hint to be lost which it is calculated to afford to the Zoologist, as he may deduce from this limitation of the powers of combining affinity an analogical reason for believing that organic species have been in like manner limited, and not left to the chances of progressive development. The progress made in Chemistry after the establishment of this leading law has been wonderful, and it may be said that the whole fabric of Organic Chemistry has been its offspring, whilst the light it has thrown on the constitution of minerals by the doctrine of substitution of simi-

larly constituted elements has tended also to raise Mineralogy to the rank of an exact science. How wide also has become its practical influence! In Agriculture, by showing the true constitution of various plants, it has indicated the value of inorganic as well as organic manures, and proved that in many cases the soil ceases to be productive from the simple exhaustion of a mineral element necessary for the growth of the plant. It has shown that the carbon of plants is principally obtained by the direct action of the leaves of the plant on the atmosphere; and when these several lessons are received and studied by the practical man, he is no longer at a loss to understand why he may obtain successive crops of some plants from the same ground, as the Botanist finds a plant on the very spot where it has flourished for ages, although his corn crops, by taking away from the ground the necessary inorganic elements, quickly render it unfitted for their continued growth. Chemistry goes hand in hand with Geology in this important practical application, and the Farmer is beginning to cast off his ancient prejudice, and to value both these sciences as his most useful auxiliaries, since they indicate to him not merely the valuable qualities of the various mineral substances which enter into the vegetable structure, but give him correct intimation where they are to be found. No chemical inquiry is perhaps more striking than that which has led to the discovery in vegetables of many of the principles which were supposed to belong exclusively to animals, and pointed out a most singular analogy between the functions of both. In plants, says Dumas, the fruit, or rather the grain, is rich in fatty matter which is destined to produce heat by its combustion during germination; in animals the fat is also kept in reserve to be used for combustion in respiration, should the supply of nourishment fall short. There is reason to believe that the fatty matters originate in the leaves, and are thence carried to the embryo to be deposited either around it, or in the seed generally. These fatty matters pass into herbivorous animals, and from them

into the carnivora, so that the supporter of combustion in the vegetable seed and in herbivorous and carnivorous animals has been elaborated in the green leaves of plants. These are facts which may well excite the admiration of the scientific and command the respect of the practical man.

But there is an element of success in every practical occupation of life which no theory can supply, namely, practical skill; and the consciousness of the necessity of such skill too often induces the practical man to overlook the fact, that skill must have been originally set in motion by science, and that what is often called a lost art, ought in reality to be styled a lost science. Every one is familiar with the mineral paint called 'white lead'—a substance known to the Ancients. Now the remarkable process by which it is obtained exhibits a high degree of knowledge of chemical principles, or, in other words, much scientific discovery at a very early period. The manufacture, according to the Dutch or common method, is thus conducted. The lead is cast into thin plates not exceeding $\frac{1}{12}$ inch in thickness, which are twisted into spirals: the plates thus twisted are then put into pots containing vinegar, the spirals resting on an internal rim in each pot. The pots are now arranged against a wall about 20 feet high, divided by planking partitions into lodges or closets 20 feet deep and 12 feet wide, the top being covered by a roof. A bed of fresh dung is spread on the ground about 1 foot thick, and over this is placed a row or layer of pots, side by side, covered with plates of lead, in addition to the spirals within them, a few pots, about twelve in each row, filled with vinegar, and having no lead, being left here and there uncovered. On each layer, pieces of scantling, 3 inches square, are placed at every second foot, and over them boards, on which another layer of fresh dung is placed, and then a second row of pots, and so on successively to a proper height, when the whole is covered with old dung, the back of the wall having, as the work progressed, been also coated with dung. The front is then closed by a coating of old dung, 1 foot thick, and that is

secured in by boards so placed as to leave ample room at the joints for the free entrance of air into the mass. The dung may be replaced with advantage by tan, which is less subject to produce sulphuretted hydrogen, by which the product is often blackened and injured. Each pot receives about $2\frac{1}{2}$ ℔s. of lead, of which the covering plates form one-half, and in each chamber or lodge there is placed about 22,000 ℔s. of lead. The operation is now left to itself for 35 or 36 days, when the crude white lead formed is detached from the lead, and by subsequent mechanical operations reduced to a marketable state.

The process depends on the following considerations: first, a moist and warm atmosphere is required for the ready oxydation of lead, and this is produced by the fermentation of the dung; secondly, the free access of air, which is obtained by the constant flow of the external air into the mass through the joints of the boards, as the rarefied air within rises and escapes at the top; thirdly, the production of such salts of lead as may be readily in part decomposed by carbonic acid, so as to form carbonate of lead (white lead), and this is effected by the vinegar, which produces a tri-basic acetate of lead, readily decomposable by carbonic acid, so as to form two molecules of white lead and one of neutral acetate of lead, when the neutral acetate, by contact with the lead and the air, is again brought into the state of a tri-basic salt, and then again decomposed by the carbonic acid, and so on whilst the process lasts: finally, the production of carbonic acid, which is abundantly effected by the fermentation of the dung or tan. In the process the temperature rises sometimes so high as the boiling point, and the carbonic acid acts on a highly concentrated or saturated solution of the tri-basic salt, which, being formed on the surface of the plates, is very probably in the state of a humid mass; and on this concentrated condition depends the opacity of the white lead formed, which is, as is well known, one of its most essential characters. It is true that more refined chemical arrangements have been adopted both in France and England to produce this valuable pigment, but it is im-

possible not to discover in the process detailed,—a process which in its results has been so eminently successful as to have given hints for the improvement of other methods,—the evidence of great scientific knowledge in its originator. The beauty and excellence of church glass during the mediæval ages seem to point to a similar possession of scientific knowledge, probably in some of those early students of Nature, the Monks; and if the art is now reviving, and promises ere long to rival its former condition, the result is due to the efforts of science aided by practical skill. These examples, then, and many others, might be cited, such as the processes of Metallurgy, and the application of electric and electro-magnetic science to the galvano-plastic processes and to the telegraph, all of which demonstrate that whilst the only sure basis on which any science can be founded is the observation of facts, or, in other words, practical knowledge, so also the sure basis of every art is science. When, however, an art has been once founded on a sound knowledge of principles or laws, practical skill may, by the tact it acquires, greatly improve and advance it, and the art may be perpetuated in the hands of those who have forgotten, or perhaps have never known the science on which it depends; and it is thus that we may often read in some refined art which has come down to us, a record of scientific labours which have left no other trace behind them.

But in no science has the value of inductive reasoning been so strikingly illustrated as in Geology,—that science which is the more immediate object of this volume: nor has any more strongly proved the importance of a sound knowledge thus acquired in advancing the practical interests of mankind. Glimpses of the formative and modifying functions exercised by both fire and water were assuredly obtained by the Ancients; for it was impossible that thinking men could contemplate the action of rivers and of the sea in wearing, transporting, and depositing the mineral matter of the earth's surface, or that they could watch the glowing flood of melted lava, as it poured from the volcanic crater, without recognizing the

power of those great agencies. To them, however, the labour of collecting facts was distasteful, and the passion of speculative theorizing was strong; so that whilst they played with the dreamy hypotheses of possibilities, by turns advancing to or receding from the truth, and sometimes anticipated discovery by conjecture, they never succeeded in establishing a correct theory of the formation of the earth. So long indeed did this spirit of speculation continue to maintain its influence, that the Baconian system only slowly made its way in Geology; and in the case of fossil organic bodies, or the remains of ancient and no longer existing animals found imbedded in the stony masses of the earth's strata, the positive evidence of the senses was rejected, and it was attempted to explain such appearances by a hypothetic plastic power in Nature which had been exercised in forming so many *lusus naturæ*. It would be useless to enumerate all the great men who have aided in dispelling the obscurity consequent on mere scholastic discussion by appealing to an observation of facts. There were two leading courses pursued by them: the one, an examination of the mineral matter of the earth's surface, with a view to determine the actual manner in which it had been arranged; the other, an investigation of the nature and history of those vestiges of animals and vegetables, which, being found in the interior of mineral masses, proved that a portion, at least, of the crust of the globe had been formed subsequently to the existence of organic beings. Lehmann, in 1756, made the first satisfactory step towards a correct knowledge in the mineral inquiry, by his description of the stratified deposits (Flætzgebirge) of the centre of Germany. Subsequent Geologists pursued the same course of careful observation, amongst whom may be specially noted the illustrious Saussure; and at the close of the last century, Werner gave new impetus to the science by generalizing the results of his own observations, and arranging them into a system. It was to be expected that the peculiar district or field of inquiry would influence materially the deductions of the first observers; and that whilst Werner

built up an aqueous theory, in which he supposed all mineral matter to be deposited from a solvent fluid, Hall, having derived his knowledge of the action of highly heated masses from the examination of a totally different country, established an igneous theory,—and that modern Geologists, proceeding on the principles so ably set forth by Sir Charles Lyell, who may be considered the founder of our present system of geological reasoning, would hesitate to reject any cause of the existence of which there is evidence in the still continuing operations of Nature, and would carefully combine together in one great system all those forces which, whether aqueous, aerial, or igneous, now act on the earth's surface, and from the similarity of effects so palpable in the ancient strata, may be assumed to have also acted at all former periods within the reach of our observation. In the second branch of inquiry the progress was even slower; for though, in 1517, Frascatoro had remarked that all the organic fossils then discovered could not have been buried at the same epoch, and Stenon, in 1669, had hinted that they might be used to distinguish the relative ages of the masses containing them, the prejudice to be overcome was so strong, that Palæontology can scarcely be said to have become a recognized branch of geological science until William Smith announced, in 1790, the design of publishing a geological map of Great Britain, which he effected in 1815, and thus promulgated the fact, that England is constituted of strata the superposition of which is constant and never inverted, and that the same fossils being found in all parts of the same bed, it may be characterized by those fossils. The genius of Cuvier shed a new and brilliant light over Palæontology by establishing the laws of anatomical composition, and under their guidance building up the remains of the higher animals, so as to exhibit to the naturalist many remarkable forms which, though they have ceased to exist, are connecting links in the great chain of the animal kingdom. Many are the great men who have continued to work out, with unceasing labour, this great subject; and it is no small gratification to

know that Greenough, Buckland, Sir H. De la Beche, Lyell, Sedgewick, Conybeare, Fitton, Phillips, Murchison, are still living amongst us, and by their inquiries and their reasonings, still add new lustre to a science which has, as it were, grown up under their care and guidance. Geology, therefore, is now a true science, being founded upon facts and reduced to the dominion of definite laws, and in consequence has become a sure guide to the practical man: the Miner finds in it a torch to guide him, in his subterranean passage, to the stratum where he may expect to find coal or iron, or to the recovery of the mineral vein which he has suddenly lost;—the Engineer is guided by it in tracing out his roads or canals, as it tells him at once the firmest stratum for supporting the one, and the easiest to cut through for the other, and makes him acquainted with the qualities of the materials he should use in his constructions, and the localities where he should seek them;—the Geographer finds his inquiries facilitated by learning from Geology the influence of the mineral masses on the form and magnitude of the mountains and valleys, and on the course of rivers;—the Agriculturist is taught the influence of the mineral strata on vegetable and animal life, and the Statesman discovers in the effects of that influence a force which stimulates or retards population;—the Soldier also may find in Geology a most valuable guide in tracing his lines both of attack and defence;—and it is thus that a science rich in the highest objects of philosophic research is at the same time capable of the widest and most practical application.

Can it be doubted, then, that there ought to be an intimate union between the practical and the theoretic man,—between the observer and the philosopher?—and is it not also evident that the position of the practical man is often most favourable for the collection of facts which are overlooked only because his mind has not been trained to observe? When the most simple practical man has observed a fact, to that extent, he has acquired knowledge and become scientific; and though he overlooks many facts, he is often imbued with more knowledge

than is supposed by the theorist. To extend his powers of observation is the object of this volume, and it is believed that every applied science will acquire additional extension and stability by availing itself of the quiet labours and sound sense of practical men.

CHAPTER II.

Geology—Its Meaning, Object, and Utility as a Science.

Geology, a treatise or discourse on the Earth, is a term which admits of a very wide interpretation, and naturally suggests to the mind inquiries: 1st, into the formation and original condition of the earth; 2ndly, into the successive modifications which it has undergone, and the agencies by which they have been effected; and 3rdly, into its present condition, and the agencies by which changes in that condition are still effected. The first object, then, of the Geologist is to establish, on the principles of inductive reasoning set forth in the introductory chapter, the science as it depends on each of these inquiries, and then to apply it to the practical purposes of life. It may be here premised that a science is practically valuable just in proportion as its facts have been discovered, and its laws established and studied; for so long as we are uncertain whether a known result has proceeded from a definite cause, we are unable to apply the fact or circumstance to the elucidation of other facts or circumstances; and so long as we are unacquainted with the properties of any substance under our examination, we cannot declare with certainty what share it may have had in the phenomena we have observed. This may be illustrated by a reference to gunpowder. Its explosive quality is the result of its composition, and we can only depend upon the results when we know that the compound has been accurately formed: to insure, therefore, certainty in the operations depending on it, we must take care that a proper standard of composition has been adhered to. In a similar manner, we can only apply Geology as a practical

science when we have ascertained and made ourselves familiar with those facts which prove the first principles on which it has been founded to be correct and stable.

To obtain any idea of the earth's formation and original condition, we must treat Geology as a branch of the physical sciences. The earth, as one of the planetary bodies revolving round the centre of our solar system, must, like all the other planets, be subject to the great laws by which they are at once retained in their orbits and caused to revolve on their axes; it is only one member of a great whole, and in its density, its volume, and its mass, is in strict relation to all the other bodies of the same system. The first formation, therefore, of the earth, or the manner in which it was probably condensed from nebulous matter, and reduced to the planetary form, may be considered a portion of Astronomical science.

It is thus that Astronomy has assisted in the determination of the form of the earth, and it is now known to be an oblate spheroid, of which the equatorial diameter exceeds the polar by 139,296 feet, or about 23 geographical miles,—a difference equal to more than nine times the height of Mont Blanc, or five times the height of the highest point of the Himalaya chain. And in like manner, by referring to the laws of matter exhibited in gravitation and attraction, the Philosopher has been enabled to weigh the earth he had before measured, and to determine its mean density as about $5\frac{1}{2}$ times that of distilled water: but the actual mean density of the solid matter of the earth's surface, its rocks and strata, does not exceed 2·9, and evidence has been thus obtained of an increase of density from the surface to the centre of the earth; and though it is impossible that man should descend so low into the interior of the earth as to discover the actual condition and nature of its mineral masses, he has, at least, obtained some clue to it from without in the falling aerolite, or meteoric stone,—the elementary identity of which with the matter of our earth,—the occurrence as one of its constituents of the mineral augite, which is an essential ingredient of subaqueous

volcanic products,—the unoxydized condition of its iron, which indicates that it had not been exposed to atmospheric agency, and its high specific gravity 3·575, that of the iron itself being 7·715,—afford us, as it were, a peep into the internal constitution of our own planet, and exhibit a general harmony in the mineral matter of the planetary bodies. In other stages of the subject there will be frequently occasion to refer to general physical laws; but if we turn for the present to the more practical investigation of the past and present state of the earth's surface, we shall soon be convinced that there is something more in its rocks and strata than mere masses of stone, or heaps of gravel, sand, or mud, confusedly thrown together: we shall find, in fact, that these deposits have been the result of forces tending, according to the ordinary laws of nature, either to break up and remove, or to deposit and consolidate in new forms the mineral strata, and that Geology is thus connected with the experimental sciences of Meteorology and Chemistry: nor is this all; for whilst we examine the mud and sands of our own coasts and seas, and either find imbedded in, or resting upon them, the relics of many living species of animals and plants, we cannot overlook the analogy in distribution and arrangement exhibited by the sandstones and clays of other epochs, and the wonderful fact that they too are associated with the relics of organic beings: we learn indeed the close connection of Geology with all the natural sciences, and are taught to view it not merely as an humble investigation of the circumstances of inert matter, but as a lofty exposition of the mysteries of organic creation.

Enough has been said to impress upon the reader the philosophical importance and dignity of Geology; and it can be easily shown that its practical importance is the result of its philosophical connection with the exact sciences. For example, were all the deposits we meet with, here rock and there sand, gravel, and clay, mere arbitrary heaps which had never been brought under the controlling influences of organic or inorganic forces, we should be unable to use the one as

an index to the history of the other, and the study of each individual deposit would end as it had begun, in itself alone. But if it be proved that certain physical agencies have, according to fixed laws, been in operation from the earliest periods of our planet's history, and that they have either co-operated with, or acted upon, organic beings, so as to check, modify, or destroy, at successive epochs, animal and vegetable life,—and if in the strata themselves we can find the fossilized relics of successive races of organized beings, and can make the one a guide to the other,—how different is the result, uncertainty now giving place to certainty, and a knowledge of the strata of one portion of the earth's crust becoming a clue to the investigation of the strata of any other. It is upon this certainty, obtained by the collection and collocation of facts from all parts of the world, that Geology rests its claim on the attention of practical men.

In order to acquire a clear conception of geological phenomena, it is necessary to take a brief review—1st, of the various elementary substances which enter largely into the composition of the earth's crust, and of the fluids connected with it; and 2ndly, of the principal compounds formed by them.

Including most of the metals, there are more than fifty substances which, having hitherto resisted the efforts of the Chemist, are still considered simple. Of these sixteen only occur extensively amongst ordinary mineral compounds, whether fluid or solid: they are, *oxygen, hydrogen, azote* or *nitrogen, carbon, sulphur, chlorine, fluorine, phosphorus, silicium, aluminium, potassium, sodium, magnesium, calcium, iron,* and *manganese,* which, combined together in various ways, compose the greater portion of the earth's crust and of its liquid envelope. The other elementary substances, though several of them, as bromine, iodine, and borine, are highly interesting, and some, as the metals are most important, do not constitute so large a portion of the whole as to require a specific notice in this part of our subject.

The important offices of some of these substances are generally known; as for example, of hydrogen and oxygen in water,—of oxygen and nitrogen in air,—of carbon as a minute but very essential constituent of air,—of carbon again as a combustible substance in turf, wood, and coal,—of iron as the most useful of metals; but in addition to these well-known offices, they have others, which are little less essential and marked, to perform in the mineral constitution of the earth's crust, the minerals of which it consists being principally formed by the combination of some of these elements with the principal metallic bases; a fact which will become evident as we consider them in order.

Oxygen combines with silicium to form silica, of which it constitutes more than a half; but silica, either pure, or combined as an acid with metallic bases, has been estimated to form almost one-half of the solid crust of the terrestrial globe; and hence oxygen, in this one condition, is equivalent to a quarter of the ponderable matter of the earth's surface. But oxygen is also combined with aluminium to form alumina, an earth which is an essential constituent of certain minerals and rocks, the decomposition of which produces the beds of clay, so general throughout the world; and when the quantity of mud or clay found in modern alluvium, and the beds of clay in more ancient deposits, are considered, as well as the strata of great thickness of mica and clay slate which extend over miles of the earth's surface, in all of which alumina is an essential ingredient,—the several varieties of clay being essentially silicates of alumina proceeding from the decomposition of the felspar and mica of granite, gneiss, mica slate, and clay slate,—the importance of alumina must be considered only second to that of silica; but of this earth, oxygen in weight forms nearly one-half. Again, oxygen forms nearly one-half of carbonate of lime, the basis of limestone, a mineral of which, in many parts of the world, mountain masses of many hundreds of feet thickness are constituted. And if we add to these instances its presence in water, which is so abundant in the

mineral as well as the vegetable and animal kingdoms, and of which it forms in weight eight-ninths, we may readily believe that of the whole crust of the earth, at least one-half is composed of this remarkable element.

Hydrogen, as a constituent of water, enters into the composition of many minerals and mineral strata, and forms a part of almost every organic substance.

Azote or *nitrogen*, as a constituent of the atmosphere, of most animal and of several vegetable substances, is an important element, although it is scarcely appreciable in the mineral kingdom. Traces of this fundamental element of animal organization are, however, to be observed, in the form of ammonia, in those strata wherein were deposited the remains of animals, and such traces have been sometimes appealed to as a test of the former presence of animals in strata which now exhibit no fossil evidence of their existence; but however striking this exhibition of ammonia may be, it is subject to so many sources of uncertainty as to be justly considered insufficient in deciding so obscure and difficult a question.

Carbon, the basis of coal, the base of carbonic acid, and the most considerable element of the solid parts of animals and vegetables, is one of the most important substances in nature; it forms nearly one-eighth part of carbonate of lime, and is therefore an essential constituent of the earth's crust.

Sulphur, a constituent of animal and vegetable substances, is exhaled in large quantities from many volcanoes, either in a pure state or in combination with hydrogen, and has evidently proceeded from some of the mineral substances with which they are connected: it is indeed visibly a part of the mineral kingdom, as it occurs in the sulphurets of the metals, and in sulphate of lime or gypsum. As regards the sulphurets, its presence is sometimes secondary, being the result of the partial decomposition of the sulphuric acid of soluble sulphates in a singular chain of compositions and decompositions. In beds of shale, iron pyrites (bisulphuret of iron) is frequently

very abundant, and when water gains access to it, there is a partial decomposition, some of the oxygen of the water combining with the sulphur to form sulphuric acid, which then combines with the iron, also oxydized from the water, to form sulphate of iron. The soluble sulphate is carried away by the filtering water, and when it comes in contact with animal or vegetable substances imbedded in the strata, is again decomposed, the oxygen combining with the hydrogen and carbon of the organic bodies to form water, carbonic acid, and carburetted hydrogen, and a sulphuret of iron being deposited in their tissues. The results of this process, as exhibited in fossil vegetables and in the organic portions of shells and fish, are sometimes very beautiful, and it may be conjectured that this succession of compositions and decompositions will yet be traced up to an earlier commencement in the more ancient geological strata.

Chlorine, as a constituent of chloride of sodium (common salt), takes part in the formation of those extensive beds of rock salt which occur in various geological formations. Chlorine forms nearly $\frac{7}{12}$ths of chloride of sodium, and is therefore another example of a gaseous body entering extensively into the composition of the earth's crust. United with hydrogen as hydro-chloric acid, it is evolved from volcanoes.

Fluorine, when combined with oxygen as fluoric acid, unites with lime to form fluate of lime, or fluor spar, which is often associated with lead in vein-stones. It is also a constituent of mica and hornblende, but it may be considered important rather in a mineralogical than geological sense.

Phosphorus.—A constituent of phosphate of lime, which is, as Apatite, rather rare in the mineral kingdom, but is a most important compound in the animal kingdom, being the mineral portion of bone, the strength and stability of which depend upon it. It is also a constituent of many vegetables, and *enters from them into the animal structure.* Darwin mentions two curious secondary productions of phosphate of lime,—one at St. Paul's Islands, where the rocks are coated with it, the

action of the spray on the dung of sea-fowl having produced phosphoric acid; and at Ascension, where stalactites of the same mineral have been produced in a similar way.

Silicium or *Silicon,* the metallic basis of silica.—The important position this substance occupies has been shown under 'Oxygen;' most of the minerals, exclusive of the carbonates and sulphates of lime which form the earth's crust, appearing in the form either of silex or of silicates. The water of springs and wells always contains a little soluble silica: in mineral waters its quantity is sometimes more considerable, and associated with an alkaline carbonate, it occurs in the hot alkaline spring of Reikum, in Iceland, and in the boiling jets of the Geyser. These latter modes of occurrence indicate the slow but continued destruction of the silicates of the mineral kingdom, and afford a probable explanation of the formation of much of the crystalline quartz in nature: on the solution of many limestones gelatinous silica is found, and its pressure indicates that a similar process was connected with their formation.

Aluminium, the metallic base of the earth alumina.—Alumina, as one of the principal constituents of clay, and of all those minerals and rocks from the decomposition of which it is produced, is, as shown under 'Oxygen,' a most important portion of the earth's crust. It is also well known as one of the component parts of alum, a salt extensively used in dyeing, which is a double sulphate of potash and alumina. The sulphate of alumina is formed naturally by the action of sulphuric acid, proceeding, as already stated, from the decomposition of iron pyrites, on the beds of clay or of shale in which that mineral is abundant. The sulphate of alumina being dissolved out, and separated by crystallization from the proto-sulphate of iron formed at the same time, is mixed with sulphate of potash, and the two combine to form the double salt alum. Alumstone, a natural product of volcanic countries, also yields, by heating, this substance: it is abundant in the ancient crater of Solfatara, near Naples.

Potassium, the metallic base of the alkali potash.—Potash is a component of many minerals, especially of felspar (a well-known constituent of granite and gneiss), of which it forms nearly $\frac{1}{6}$th part. The potash in this mineral is in the condition of a silicate, and the soil is provided with the potash necessary for the support of various plants from the decomposition of rocks containing felspar. From the artificial destruction of these plants the potash used in the arts is obtained, and it has therefore obtained the name of vegetable alkali. It is the base of the important mineral compound, nitre or nitrate of potash, which will be further noticed.

Sodium, the metallic base of soda, an alkali which replaces potash in albite (soda felspar).—Soda has been called the mineral alkali, in contradistinction to potash, but such a mode of distinction is now known to be groundless. Carbonate of soda is obtained from kelp, or the ashes of calcined sea-weeds, and might therefore, as a secondary product, be also called vegetable. Soda is likewise found in all animal fluids, and the base itself is widely diffused in that most valuable salt, the chloride of sodium, or common salt. Nitrate of soda abounds in Peru.

Magnesium, the metallic base of the earth magnesia.—Magnesia, as a silicate, is a component of many important minerals, especially of pyroxene or augite, of amphibole or hornblende, of steatite, and of serpentine. Of hornblende it forms $\frac{1}{8}$th part. It is also remarkable as a carbonate in dolomite, or magnesian limestone, a combination of the carbonates of lime and magnesia which is very extensively diffused in nature, and forms occasionally mountain masses. The effect of magnesia on vegetation is well known. As a carbonate, it would in itself perhaps be innocuous, but as it forms on decomposition very soluble salts, it may be carried into the vegetable organism, and thereby prove injurious. As an alkaline earth it is dangerous from continuing so long in a caustic state.

Calcium, the metallic base of the earth lime which forms more than a half of carbonate of lime.—It is unnecessary to

dwell on the vast importance of the latter mineral, both as an economical substance and as a constituent of the earth's crust; but lime is also found as a component of another valuable mineral—sulphate of lime, or gypsum, of which it forms about ¼th part. Gypsum occurs in extensive beds in more than one geological formation; in America in the primary or Silurian, in England and Ireland in the secondary, and along the Mediterranean in the tertiary strata, divisions which will be hereafter explained. Lime also enters into the composition of a great variety of minerals.

Iron.—The mere name of this metal must recall to memory the multitude of uses to which it is applied, and justify us in regarding it as one of the greatest gifts of creative intelligence to man. In addition, however, to its occurrence in a mineral state in our coal measures, as clay iron-stone and also as spathic iron, both of which are carbonates of iron; in masses and in disseminated nodules as anhydrous and hydrated peroxide of iron, or red and brown hematite; in the magnetic oxide and in specular iron, or Elba iron,—minerals which as ores are smelted for iron,—it is found almost pure in masses of meteoric iron and in a vein traversing mica slate in North America. In combination as an oxide, it is extensively diffused, being found in small quantities in most minerals, and consequently in the soil of the earth's surface. It occurs in many springs, being dissolved as a protoxide by water charged with carbonic acid, and then again deposited as a peroxide, either at the bottom of marshes, as bog iron, or on the banks of the springs: and it is deserving of notice that this apparently simple operation is, in reality, compound; the tangled masses of this substance, so frequently found in such situations, proving on examination to be the work of an infusorial animal, —the gaillonella ferruginea,—which thus interposes and reduces the mineral to an animal substance. This metal is also found in the colouring matter of the blood, of the hair, and of many other tissues, both animal and vegetable, and its uses are not therefore limited to the great works of art,—the machinery of

civilized social life,—but are traced also in the many charms which are shed over life itself, by the varied colours assumed, under the control of creative power, by the petals of the flower, the egg and feather of the bird, or the skin of man and other animals.

Manganese enters into the composition of a great number of minerals, though often in a very small quantity, forming, in such cases, their colouring matter. It is also found in the ashes of plants and the bones of animals. It is used in the arts,—for preparing chlorine by the action of its peroxide on hydro-chloric acid, and oxygen by the action of the same oxide on sulphuric acid, as also to render glass colourless by its oxydating action, and as a deutoxide to colour glass purple.

These, then, are the simple elementary substances which have been combined together in that portion of our globe which, by the long-continued action of meteoric agencies, has been reduced to a condition suited for the support of animal and vegetable organization. They will now be considered in the compounds which form the strata of the earth, and which we shall not be surprised to find few in number, when we reflect that a multitude of animal and vegetable substances, many of which are possessed of the most opposite qualities,—some being alkalis, some acids, some poisons, some wholesome food,—have all been compounded of the four simple elements, carbon, oxygen, hydrogen, and azote. One point, however, is here deserving of especial notice, as bearing on the great question of the former condition of our globe; namely, that $\frac{2}{3}$rds of the ponderable matter of the earth's crust, taking into consideration oxygen, hydrogen, and carbonic acid, have existed, or been capable of existing, in a gaseous state.

2. The principal minerals which enter into the composition of rocks, and of stratified beds, are — quartz, felspar, mica, augite, hornblende, oxydulated iron, carbonate of lime, sulphate of lime, double carbonate of lime and magnesia or dolomite; chloride of sodium or rock salt, coal, and lignite. Many other minerals occur occasionally in rocks and sedimentary deposits,

and impress upon them a consequent peculiarity, such as garnet in mica schist, tourmaline in some varieties of granite, flints in chalk and other calcareous formations, iron pyrites and carbonate of iron in shales, crystallized carbon or the diamond amongst the gravel and other transported or alluvial matter along the Ghauts in India (especially at Golconda), as also in Borneo and in Brazil; but these, as well as the vast variety of minerals found in the basaltic lavas and trachytic lavas of both ancient and modern volcanoes, and those either associated with metallic ores or isolated in mineral veins, although replete with interest to the Mineralogist, and often of great value to the carefully inquiring Geologist, are insignificant as to quantity, when compared with the minerals cited as the principal constituents of the earth's crust.

The composition of these minerals may be represented in a tabular form, as in the opposite page, and to them, as principal elementary substances, may be added the alkali lithia, its name, derived from the Greek λίθειος, having been adopted from its first discovery in an earthy mineral, though it occurs only in small quantity in rocks. The metallic base lithium was obtained by Davy from the alkali; its equivalent is very low, 6·44, and its oxide has therefore a high saturating power. The discoverer of the alkali was Arfwedson, in 1818. Rock salt may be considered a compound of sodium 40·5 and chlorine 59·5, or according to the old view, 53·29 of soda and 46·71 of muriatic acid, but it is usually contaminated by a small quantity of extraneous substances,—the salt of Cheshire containing—

Muriate of soda	98·32
Muriate of magnesia	0·02
Muriate of lime	0·01
Sulphate of lime	0·65
Undissolved matter	1·00

Coal and lignite vary considerably in composition. Blind coal, culm, or anthracite, contains for example from 94 to 97 per cent. of carbon mixed only with mineral matter, as bitumen

SPECIES AND VARIETY.	Silica.	Alumina.	Lime.	Magnesia.	Potash.	Soda.	Oxide of Iron.	Oxide of Manganese.	Carbonic Acid.	Sulphuric Acid.	Water.	Fluoric Acid.	Lithia.
Quartz (when pure)	100	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,	,,
Felspar (green, of Siberia) .	62·83	17·02	3·00	,,	13·00	,,	1·00	,,	,,	,,	,,	,,	,,
Do. (Carlsbad)	64·50	19·75	trace.	,,	11·50	,,	1·75	,,	,,	,,	0·75	,,	,,
Do. (soda or Albite, of Finbo)	70·48	18·45	0·55	,,	,,	10·50	,,	,,	,,	,,	,,	,,	,,
Do. (Albite, of Chesterfield) .	70·68	19·80	0·23	,,	,,	9·06	,,	,,	,,	,,	,,	,,	,,
Mica, or talc-mica, (Zinnwald)	47·00	20·00	,,	,,	14·50	,,	15·50	1·75	,,	,,	,,	,,	,,
Do. (2nd Zinnwald variety) .	46·23	14·14	,,	,,	4·90	,,	17·97	4·57	,,	,,	3·73		4·21
Do. lepidolite (granular or scaly mica)	50·35	28·30	,,	,,	9·04	,,	,,	1·23	,,	,,	5·20		5·49
Augite (green)	54·08	,,	23·47	11·49	,,	,,	10·02	0·61	,,	,,	,,	,,	,,
Do. (black)	53·36	,,	22·19	4·99	,,	,,	17·38	0·09	,,	,,	,,	,,	,,
Hornblende (green, Pargasite)	46·26	11·48	13·96	19·03	,,	,,	3·43	0·36	,,	,,	,,	1·60	,,
Do. (black)	45·69	12·18	13·85	18·79	,,	,,	7·32	0·22	,,	,,	,,	1·50	,,
Oxydulated iron	,,	,,	,,	,,	,,	,,	peroxide, 2 atoms; protoxide, 1 atom.	,,	,,	,,	,,	,,	,,
Carbonate of lime (when pure, as calcareous spar) . . .	,,	,,	55·93	,,	,,	,,	,,	,,	43·58	,,	,,	,,	,,
Sulphate of lime (gypsum) .	,,	,,	33·00	,,	,,	,,	,,	,,	,,	44·80	21·00	,,	,,
Do. (anhydrite)	,,	,,	41·75	,,	,,	muriate, 1·00	,,	,,	,,	55·00	,,	,,	,,
Dolomite (by Thomson) . .	,,	0·68	30·54	22·91	,,	,,	1·69	,,	48·22	,,	,,	,,	,,

has either not been developed in it, or has been subsequently removed, though traces of vegetables have been discovered even in anthracite; it is therefore a non-flaming coal, and yielding an intense heat, is particularly valuable for the lime-kiln and similar purposes: the coal of Kilkenny in Ireland and the culm of Wales belong to this division. Newcastle coal is a flaming or bituminous coal, consisting, in the best varieties, of carbon 84·99, hydrogen 3·23, oxygen 11·78, bitumen having been developed in its substance by the action of oxygen and hydrogen on a part of its carbon. Lignite still exhibits the structure of wood, and may be considered a fossil charcoal.

Attention should be also paid to the variation of elements in varieties of the same mineral, a fact which is constantly occurring in Mineralogy and is explained by the chemical theories of substitution by equivalents, and of isomorphism. It is thus that substances possessing the same elementary constitution may replace each other in a mineral, without disturbing its principal or characteristic qualities; for example, alumina is possessed of the same elementary constitution as peroxide of iron, namely, it consists of 2 of base to 3 of oxygen, and can thus replace it; and magnesia, possessing a constitution of 1 of base to 1 of oxygen, can replace the protoxide of iron. In green and black augite this variation in the bases is well exemplified: as,

Green augite,—magnesia $11·49 +$ prot. iron $10·02 = 21·51$
Black augite,—magnesia $4·99 +$ prot. iron $17·38 = 22·37$;
the chemical composition varying, and yet the formula of composition being preserved.

As it is difficult to convey fully to the mind, by written description, the physical characters of minerals to the student, it is recommended to obtain accurately named specimens: the following remarks may however be of use when combined with the subsequent description of rocks.

Quartz is well known as rock-crystal, which is often called diamond, as Cornish diamond, Bristol diamond, Quebec diamond, although it has not the slightest relation to that

mineral; and also as common quartz. The prevalent colour is white: when pure it is either transparent or translucent; when impure it is commonly opaque. Its lustre is vitreous, inclining in some varieties to resinous. The streak is white.

Felspar.—Prevailing colour white, sometimes grey, and in many granites and syenites flesh red; transparent, translucent, or almost opaque; lustre, vitreous inclining to pearly on the faces of cleavage.

By observing the tendency to a resinous lustre in quartz, and to a pearly lustre in felspar, these two minerals may generally be distinguished from each other without difficulty.

Mica.—Prevailing colours, white, grey, yellow, dark brown, or black; transparent and translucent, especially in thin laminæ; lustre, pearly; flexible and elastic when in laminæ, by which character it is distinguished from chlorite and talc. This remarkable mineral is at once recognized in granite, gneiss, and mica slate, by the brilliancy of its plates or laminæ.

Augite.—Colour varying from green or grey to brown and black; generally opaque; lustre, vitreous inclining to resinous; brittle. This mineral is very common in volcanic rocks.

Hornblende.—Prevalent colour, shades of green, increasing in intensity up to black; generally opaque; lustre, vitreous inclining to pearly in light-coloured varieties. Brittle when isolated, but when massive frequently tough, and therefore difficultly frangible. It is an essential ingredient of syenite and greenstone, and occurs frequently in granite, gneiss, and other mountain rocks.

The two last-named minerals are reducible to the same chemical formula, as they are both bisilicates of lime and magnesia, in which a portion of the acid or silica is sometimes replaced by alumina, and a portion of the base by protoxide of iron, according to the law already noticed: they are also an example of dimorphism, the crystalline forms being different. The difference of geological position will enable the inquirer to judge in most cases whether he is examining the one or the

other; but as it is sometimes very difficult to determine whether a rock should be classed with greenstone or with basalt, so it is also difficult to distinguish between these two minerals. In general the species hornblende contains less lime than augite, and is less fusible; but as might have been supposed from the similarity of their elementary constitution, it is possible, by adopting certain conditions of heating and cooling, to change the external crystalline form of the one into that of the other; an experimental fact which has been used in explanation of the difference of their ordinary position.

Oxydulated Iron or *Magnetic Iron*, a compound, according to Berzelius, of 2 atoms of peroxide and 1 atom of protoxide of iron.—It is highly magnetic, and when massive, more so than any other ore of iron. Colour, iron-black; opaque; lustre, metallic. It forms extensive beds in Norway and Sweden: at Dannemora the beds are excavated to the day, the principal mine forming a chasm of one hundred and fifty feet broad, and five hundred feet deep. The amorphous masses of Siberia and the Hartz, which yield the most powerful natural magnets, may be associated with this species.

Carbonate of Lime, and also Double Carbonate of Lime and Magnesia, or Dolomite.—The presence of carbonic acid can always be determined by the action of an acid and the consequent ebullition produced by the escape of the carbonic acid. This is the easiest and most certain method of detecting limestone.

Sulphate of Lime—distinguished from carbonate by not effervescing with acids; and from other minerals, whether in its fibrous or lamellar state, by its comparative softness.

Of salt, coal, and lignite, it is unnecessary to say more under this head.

Such are the minerals which enter extensively into the composition of the earth's crust; and in order to form a clear idea of its present and past condition it is necessary to inquire under what combinations they usually occur.

A survey of any extensive portion of the earth's surface

will generally bring before us two distinct forms of mineral matter; the one, in which the mineral constituents are combined together in distinct crystals, which to the eye exhibit no traces of any previous wear, and produce therefore crystalline rocks; the other, in which the constituents have undergone wear, and are either mixed together confusedly or separated into distinct beds, but whether loosely aggregated or cemented together, indicate the action of various meteoric and mechanical agencies, and are formed into rocks, evidently of deposition, whether mechanical or chemical. To the first class belong—granites, syenites, greenstones, basalts, gneiss, many varieties of mica slate, granular limestone; to the second—sandstones, conglomerates, shales, clays, compact limestones; and if these forms were always distinctly marked, the divisions would be sufficient and satisfactory: but when the crystalline rocks, formerly called primary, are examined, they are observed closely to approach the sedimentary, as for example, mica slate and clay slate, some varieties of which are little more than a highly indurated shale; and when true sedimentary rocks in the vicinity of ancient lavas are examined, a change is observed in their characters which assimilates them to the crystalline rocks, and such is the case even in strata full of organic remains. On observations of this description the metamorphic theory has been established: it will be again referred to at a future stage of our subject.

If the Geologist, having by a careful scrutiny determined the nature, as to composition and physical characters, of the various rocks he meets with, were now to proceed to explain their occurrence on hypothetic assumptions, he would fall into the speculative errors of his predecessors; but he pursues a different course, and wisely determines to ascertain, also by observation, what forces are still in action on the earth's surface, and what effects are produced by them on its mineral constituents. He thus observes lavas issuing from volcanic craters, the effect of igneous fusion, and sand and mud banks, still forming, the effect of aqueous agency; he discovers

in the uplifting and fracturing action of the earthquake, in the wearing action of the sea wave, in the accumulating labours of the polypes, as exhibited in the coral banks, so many auxiliary or modifying forces, and he cannot tread on the sea-shore without noticing the exuviæ or remains of shell-fish and other animals becoming invested in the deposits of sand or mud forming over them; and when, thus trained to observe, he turns to the rocky strata of the earth now become dry land, he is surprised to find similar evidence of igneous action and of sedimentary deposition, whilst the analogy is further strengthened by the discovery of animal remains imbedded in their substance.

The metamorphic theory facilitates the application of recent analogies in explaining the condition of crystalline rocks which may be assumed to have been either the result of direct igneous action, producing a species of fluidity, as in lavas, and probably in some granites and porphyries; or of the indirect action of heat, on sedimentary deposits, continued for a long period and combined with pressure, producing a crystalline or semi-crystalline re-arrangement of the mineral particles, as has been the case in the crystalline schists, and in some other strata the physical condition of which has been altered, although the existence of organic bodies still demonstrates their former sedimentary character. By the careful examination of recent and still recurring natural phenomena these truths have been made manifest; and it is by the continuance of such examination that the still remaining difficulties will be removed: for example, it is highly probable that in the great basaltic district of Ireland all the beds are not eruptive, but, on the contrary, that some are metamorphic, just as in the vicinity of modern volcanoes, beds of tufa and of ashes are covered by streams of lava. The change produced on mineral beds by contact with highly heated matter has indeed been demonstrated, almost with mathematical precision; and though it is very difficult to decide its exact limitation, we

can never satisfactorily study the strata of the earth without referring to it. And if the metamorphic theory thus aids us in studying the varying mineral conditions of the earth's crust, the organic remains still visibly imbedded in many of its beds demonstrate that changes equally striking have taken place in the successive organic inhabitants of its surface; in short, that there have been animal and vegetable as well as mineral epochs. The beautiful combination of facts on which Palæontology now rests, as one of the most sure bases of geological science, can only be fully appreciated by careful study; but in this brief memoir it must be admitted as a truth, that at those various epochs of change on the surface of our globe, when the mineral strata were affected deeply and widely, shales and slates, sandstones and conglomerates, limestones, &c., being formed, some in one place, some in another, great modifications also took place in organic beings. If this conclusion be true, and it rests on facts observed over a large portion of the earth, it must be admitted that the evidence of the epochs of mineral change ought to harmonize with that of the epochs of organic change, and hence that the study of the one may be made to assist that of the other.

This remarkable deduction has in a few years elevated Geology almost to the rank of an exact science; and it may be hoped that a more extensive study of the operations of the great physical forces which still act and always have acted on the earth's strata, such as magnetism, or electro-magnetism, will render it so practically exact, that not only the probability (under any conditions of strata) of discovering certain useful products may be at once stated, but the more abstract and obscure questions of mineral veins and of the distribution of metals be also solved on sound principles.

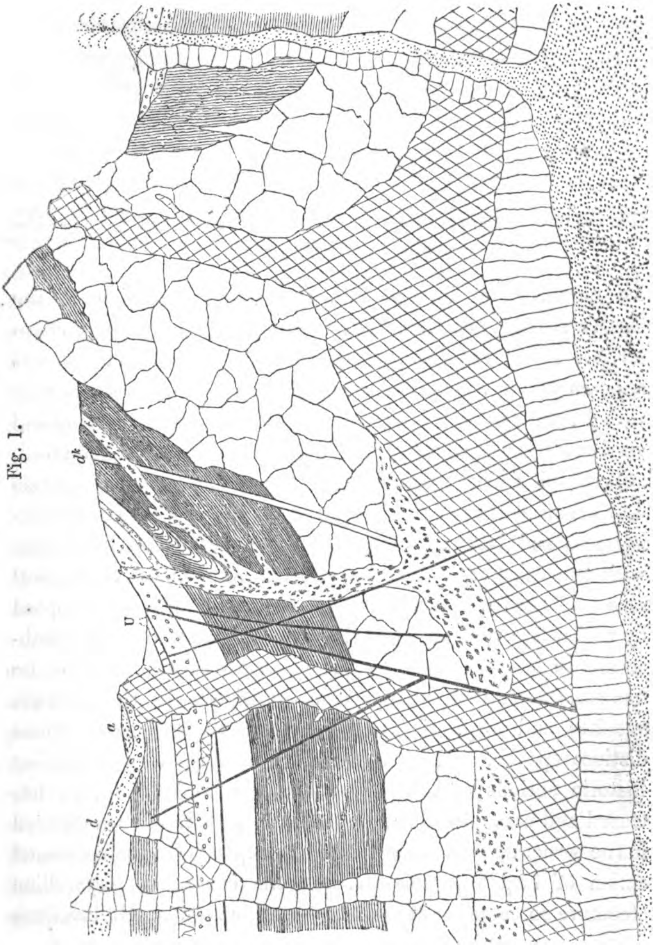
On the combined testimony of all these different classes of facts, it may then be affirmed, that as mineral matter can now in volcanoes be brought into that state of semi-fluidity which allows of the crystallization of minerals, so may it at

former epochs have undergone a similar fusion, and hence that truly igneous rocks may at such epochs have existed, and have been brought nearer to the surface, or even erupted; —that, in a similar manner, the changes produced by slow igneous action under great pressure, having been observed in strata contiguous to modern and ancient lavas, they may be admitted to have occurred in strata contiguous to other igneous rocks, giving rise to schistose crystalline rocks in all their varieties, and more or less modifying the structure of many other sedimentary deposits;—and finally, that changes in the combinations of organic beings, having been proved by extensive observations to have occurred at successive epochs, a knowledge of the particular group of animals or plants connected with the mineral strata of any one portion of the globe becomes a clue to determine the relation of such strata with those of any other portion in which the organic constituents have been previously studied. The certainty thus attained constitutes the value of Geology as a practical science; and though a careful scrutiny is yet required to remove mere varieties from the lists of characteristic fossils, and to determine the actual limits of species, it must be admitted that the modern applications of the science have been most useful and satisfactory. A general representation of the combined theories of igneous rocks, metamorphic rocks, and fossiliferous deposits, is given in the ideal diagram, fig. 1, extracted from Cotta.

In the diagram, granite is represented as an igneous rock near to the surface, and having its origin at no great depth; and that this is probably the true state of the case will be subsequently shown, the low specific gravity of ordinary granites being a strong argument against their formation at great depths, or under great pressure. It varies from 2·5 to 2·7, whilst that of the lavas of Ætna, Stromboli, and Vesuvius, is 2·9, and that of basalt above 3.

Theoretic Section of the Earth's Crust.—From Cotta.

Fig. 1.



L	Lavas ancient and modern.	F 4	Trias or new red.
B	Basalt.	F 5	Jura, including lias.
P	Porphyry.	F 6	Cretaceous.
G	Greenstone.	F 7	Tertiary.
G 2	Granite.	*d*	Diluvium or drift.
S	Crystalline schists.	*a*	Alluvium.
F 1	Cambrian and Silurian.	U	Mineral veins.
F 2	Devonian and Carboniferous.	*dk*	Dyke.
F 3	Magnesian limestone.		

CHAPTER III.

GEOLOGICAL FORMATIONS—Their Meaning, Object, and Utility—The Mode of Studying them.

IN pursuing an inquiry into the actual condition of the earth's surface, the Geologist, as stated in the preceding chapter, has discovered that the mineral matter of which it consists appears under characters so different as to point to equally varied circumstances in its production. He has thus noticed various alternations of beds or strata which, however indurated, still exhibit a close resemblance to the muds, sands, and gravels now accumulating at the bottom or on the shores of the existing seas and lakes; he has compared the ancient limestones with the calcareous deposits and the coral banks of tropical seas; he has traced the affinity between the lavas now erupted by still active volcanoes and the streams poured out either subaerally or sub-aqueously by the volcanoes of other times; he has ascertained that the crystalline massive rocks, the granites, syenites, and porphyries, were brought to the surface at various distinct epochs, and were therefore connected with distinct historic periods of the earth's changes; and finally, he has traced and exemplified the alterations which have been effected in the structure of mere sedimentary deposits by the combined action of heat and pressure, and the consequent crystalline structure so common in the metamorphic rocks. He has done all this, and yet he might not have been able to conclude from any of these facts, or from the proofs of sequence and progression afforded by the alternations and changes he had observed, that Geology, passing beyond the history of man's occupancy of the earth, opened out the records of times long antecedent to his existence. But he has found in his

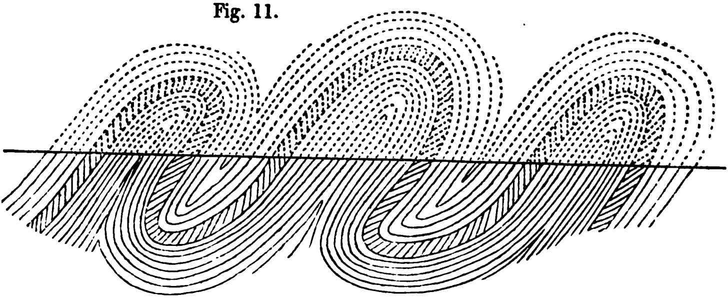
researches other evidence, and whilst apparently engaged only in the examination of the actual mineral structure of the earth, he has fallen upon the traces of its former inhabitants; and though his first and natural tendency was to call the shells and other organic relics he found by names, such as cockles, &c., which assimilated them to existing shells,—just as "the emigrant to a foreign clime bestows on its fruits and flowers the names familiar to him in his own,"—and to explain their anomalous position on land by referring to that great historic fact, the Deluge, it was not possible that a careful scrutiny of the circumstances under which they occurred could long leave him without a suspicion of their true bearing on geological history. When, for instance, the inquiry extended from such fossils as were scattered over the surface or were imbedded in loose strata to those which were so intimately mixed up with the mineral matter as to form an essential part of vast accumulations of solid rocks, such as slates, limestones, &c., he felt that no single cataclysm or event could account for their existence and position. More careful scrutiny, whilst it explained the cause of those changes which had affected their original organic condition, discovered also a crowd of differences in organic form and structure, until at length the prejudice which still sought to explain by the *plastic power* of Nature such supposed anomalies was dispelled, and the magnificent truth became apparent and recognized, that Geology dealt with the history of past as well as of present creations. This truth, though previously imperfectly developed, was first set before the British student in a clear and distinct form by the late William Smith, who, having with great labour traced out the continuity of many of the British strata and studied the peculiar fossils which each well-marked stratum contained, boldly announced as a fact,—which may be thus stated,—that

1. The fossils found in any stratum must be considered as the relics of animals living at or about the time when that stratum was deposited or formed.

2. The strata not being parts of one confused mass, but fol-

more simple way, as it represents these alternations to be the foldings of the strata in contortions, many of which are still visible, whilst others have been truncated by denudation, in the manner shown in No. 11, the surface having been further modified, by subsequent wear and the removal of the softer strata, so as to form mountain and valley.

Fig. 11.



Contorted strata, removed, above the line, by denudation.

Undulating beds were frequently formed during the carboniferous period, and the descending or dipping portions have sometimes been so perfectly truncated by denudation as to exhibit on the surface of the soil a horizontal plane. In the shales of this formation, numerous striking examples may also be found of wear, prior to the deposition of the overlying beds, by which the observer is enabled to trace the direction of the current which produced them.

The section by Dr. Lusser, taken in the Alps from St. Gothard to Asti, on the Zugersee, a portion of which is figured at page 44, fig. 9, is replete with fine examples of contortions. The strata, although greatly changed by metamorphic action, are not older than the secondary period, as they contain cretaceous fossils: they are, as usual, in immediate connection with the crystalline schists, especially gneiss; and it seems probable that some partial modification of structure, whether from heat or other cause, must have preceded their disturbance, so as to endue them with sufficient tenacity to bear such contortions, extending here to bends of 2000 feet

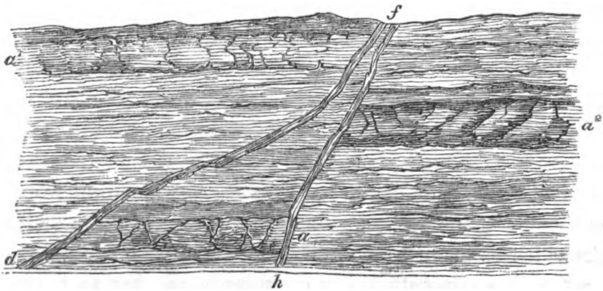
in extent, whilst the hollows cut in their summits indicate also great denudation even at very high elevations.

The contemplation of such facts prepares the observer for the vast amount of denudation he will find displayed before him. It has gone on at all periods, and wherever one formation is laid bare by the removal of the overlying strata, evidences of its previous wear may be discovered.

FAULTS.

The preceding phenomena have implied lateral movements and pressure, accompanied or followed by extensive denudation or wear. The present are the result of vertical movements, by which whole masses of dislocated strata have either slid down or been forced up, the same strata appearing thus, as if repeated, at a higher or lower level. In this case, then, the retaining force is lateral, and the moving force either directly vertical, or indirectly so, as the result of lateral pressure; and it is probable, from the frequency of faults in shale districts, that the sliding was similar to that of land-slips. In fig. 12, the bed *a* has been first up-thrown along the line or fault *d f* to a^1, and subsequently down-thrown along the fault *f h* to a^2, the corresponding portion of *a* being depressed below *h*.

Fig. 12.



Although great and striking, the actual amount of vertical disturbance, as exhibited in faults, is small compared with the lateral displayed in contortions. In the Newcastle coal district, the upward or downward movement has amounted to nearly 1000 feet, so that the surface must have been originally

affected to that extent, portions having either risen or sunk 1000 feet above or below the rest, although these projections or inequalities have been subsequently removed by denudation, and their former existence can only be discovered by studying the internal structure of the underlying strata. On every side, then, and at every level, whether we look at the varied surface of our earth as it now exists, and as it is now exposed to the incessant wear of rains, of torrents, of rivers, and of seas,—or seek our information of its condition within the deep recesses of the excavated mine,—we find the same tale narrated, of continued disturbance and wear on the one hand, and of renewed formation on the other.

ANALOGY OF MODERN AND ANCIENT SEA CLIFFS, SEA BEACHES, GLACIERS, AND ICEBERGS.

So long as the worn materials of the earth's original crust occur in deposits unaccompanied by any evidence of the existence of air-breathing animals and plants, it is not to be expected that the action of waves on the sea cliffs, which depends on a partial exposure of the surface above the level of the sea, should be discovered. The vast beds of sandstone and conglomerate which prevail at certain geological epochs are records of extensive wear and equally extensive deposition; but if taken alone, their type would be sought in the accumulations of sand and gravel which now constitute submarine banks. The extent of known sea banks would be sufficient in every respect to support and confirm such an analogy; for example, the banks of Newfoundland and the Bahama bank; and when it is considered that soundings of only moderate depth are obtained on these banks in the midst of the ocean, they may be fairly considered as analogous to and commensurate with any of the more ancient banks which now constitute our beds of conglomerate or of sandstone. This comparative view suggests to us, that as ancient conglomerates were the result of gradual accumulation, as proved by the alternations of sand and gravel which they exhibit, so are our modern banks in course of extension by the action of marine currents, which, combined with floating fields

and bergs of ice, convey to them the detritus of other regions. In the hydrographic instructions issued by the Admiralty, it is enjoined that the deep sea lead shall be cast at convenient periods, even where no shoal is either known or suspected to exist; and much valuable information will be thus acquired, as data for determining the progress and changes of such deposits. Every time the lead touches the bottom, a point of comparison is obtained, and a datum for future investigation secured; and when a shoal is first discovered, preceding voyagers ought not to be blamed because it had remained unknown, as it is at least probable that in their time it had not been raised within the reach of ordinary soundings.

If it were in our power to examine the internal constitution of sea banks, the occurrence here and there of the trunk of a water-logged tree, or of the hard fruits even of many plants, would not surprise us; but if we found beds of lignite or fossil wood, we should be obliged to admit that the bank had either been exposed to the air, and supported a growth of air-breathing plants, or had been formed in some ancient estuary, adjacent to rivers whose banks had been clothed with trees. In a similar manner, though the occurrence of fragments of anthracite in ancient rocks might render it probable that other parts of the earth at the time of their formation supported a growth of plants, it would not prove that such rocks had been exposed; but the existence of beds either of lignite or of coal in a formation does prove that its strata had either been covered with plants or were contiguous to other parts of the earth then covered with them. Such is the evidence afforded by the ancient beds of anthracitic and bituminous coal of the carboniferous and other strata, and of the lignites of the still more recent tertiaries; and it is thus demonstrated that at a very remote geological epoch, some portion of the earth's surface had already emerged from beneath the water,—a fact which is further proved by the exhibition even in the crystalline schists of that description of wear which, from the surges of the ocean beating on the shore, gives rise to our sea cliffs and our gravelly or sandy beaches.

Without, however, referring to obscure indications of vegetable life and of the existence of dry land, the vast deposits of carbonaceous matter in the coal of North America, of Australia, and of Europe, must remove all doubt upon the subject; and for the present purpose the inquiry may be restricted to the latter. The old red sandstone which underlies the coal strata penetrates into the recesses of the mica schist, in districts where the two are in contact. The character of the wear of the crystalline rocks, and of the fragments broken from them which exist in the old red sandstone conglomerates, shows that the former had sometimes attained their crystalline condition prior to the deposition of the latter. The broken and rugged edges of the mica schist are in accordance with the natural wear of such a rock; and on ascending to the coal series, the beds of shale display even more strongly the progress of wear, whilst the presence of deep beds of coal manifests, that prior to their formation or deposition, forests of tropical plants, and therefore dry land, had existed in their vicinity. It is often difficult to trace the cliffs or sea boundaries of these ancient periods, as most of the strata have again been submerged and covered by more recent strata; but as the presence of large pebbles of mica schist in the conglomerate formed in the ancient bays or recesses of that rock proves that a sea then beat against it, so may some of the greater faults of the carboniferous strata have been due, as before suggested, to ancient land-slips; and as deep precipitous banks are also not uncommon in this formation, the sea may have hollowed out the space now a lake, as in the case of Lough Erne, in Ireland, where an ancient sea bottom may be observed in the limestone of its shore, which is covered with projecting corals, now exposed by the removal, from denudation, of the shale above it, just as the sea bottom in warm climates is covered over by corallines. Indications of shore wear may be acquired at every geological epoch; but after the deposition and consolidation of the chalk it becomes more apparent, as the strata subsequently deposited were less extensive and more local. Sir C. Lyell

gives several examples of inland chalk cliffs which occur in Normandy, but none can be more striking than the curved escarpment of chalk which bounds the plain of Dungiven, in Derry, the tertiary clays with their marine shells occurring below it, and demonstrating in the most striking manner the existence of a former sea bottom, at levels now raised by elevation 200 feet above the present sea, and that at a time when the sea cliff was, as it now is, chalk.

We seem therefore in such examinations to have commenced the actual history of the earth; and as we advance further into the light of recent day, new evidences of continued change are met with in the occurrence of sea beaches still more modern in date, although they are now far removed from the action of the existing sea.

In the cave of Uddevalla, in Sweden, very striking evidence of this change of level was long since noticed in the existence of cirrhipeda adhering to its walls, the same as those which now attach themselves to the rocks of the sea shore; and we are thus, both by the evidence of mechanical wear and of organic relics, carried back step by step to ages which, though beyond the reach of historic records, can by such means be compared with the present; and when the organic links of identity are lost, we can still trace in mechanical effects the working of similar causes up to the remotest epoch. The enormous wear effected during the last pause of elevation may prepare us to comprehend that of former epochs; for example, that manifested in the present condition of Portland Island, cut off from the main land by the undermining of its more solid strata, consequent on the removal of an underlying blue clay. At present, the Chesil Bank, an accumulation of sand and gravel, forms a natural breakwater, and lessens, though it does not stop, the progress of wear; but should another slight elevation bring up the blue clay nearer to the water's edge, the wear would advance again with rapidity, and the island once removed, the Chesil Bank itself would speedily be destroyed, and the sea advance upon the main

land. This case is of much practical value; the wear of Portland Island is comparatively diminished, because the dip of the beds is such as to carry the subjacent clay to a depth beyond the action of the moving wave, and to reduce the wear to that of the more solid rock: the Chesil Bank has been formed because the remaining portion of solid rock projecting forward checks the force of the current, and causes the deposition of the pebbles moving with it: the pebbles of the bank protect the subjacent clay from further wear, and thus the general tendency is to preserve a tottering equilibrium, which the slightest change will destroy. In this instance a renewal of elevation would lead to renewed destruction; in others, elevation may bring up a solid stratum, and it would then retard such destruction, and these varying results must have attended elevation at all geological epochs; and again, if elevation, at least for a period, has stopped extensive wear by bringing up and opposing to the efforts of the sea firmer rock, depression may have produced the same effect by removing a soft stratum from its action; and at Portland the removal of the blue clay beyond the action of the waves was probably the result of a depression. In examining any coast, therefore, with a view to judge of its probable permanency, the following particulars should be especially noticed: 1st, the nature of the shingle or gravel, as showing the direction of prevailing currents; 2ndly, the prevailing and most powerful winds; 3rdly, position and character of any barrier sheltering from the prevailing winds; 4thly, position and character of any barrier opposed to the prevailing current.

Some of these modifying causes may even yet be traced in the ancient or raised beaches of former and not very remote epochs, and without doubt many such beaches have been swept away, an alteration of level, by elevation or depression, having favoured the work of denudation; and to bring the processes of wear on the one hand, and deposition on the other, to an equilibrium, the forces producing them must be in a state of balance, as an alteration in the one must lead to a change in the others.

Similar vestiges of ancient river as well as lake wear may also be discovered: of the former, an example is given in fig. 13 and fig. 14, at the end of the chapter, in which the former bed of the river Burnthollet, county of Derry, appears to have been 10 feet higher than its present course, as shown by the remarkable masses of rock still remaining to attest the ancient wear of its waters: of the latter, the parallel roads of Glenroy, so often quoted, may be again cited here. These roads are ancient shelves or beaches, formed at the margin of a former lake, and at levels corresponding to its successive depressions. The highest is 1250 feet above the sea, the next about 1000, and the third 50 feet lower. Sir C. Lyell remarks, that "among other proofs that the parallel roads have really been formed along the margin of a sheet of water, it may be mentioned, that wherever an isolated hill rises in the middle of the glen above the level of any particular shelf, a corresponding shelf is seen at the same level, passing round the hill, as would have happened if it had once formed an island in a lake." The great lakes of America exhibit similar lake beaches at various elevations above their present surface; the absence of marine shells concurring with other circumstances to remove such accumulations from the list either of ordinary marine beaches or of sea banks.

But in addition to gravel deposits of this kind, the researches of Agassiz have added others,—the effects of ancient glaciers. It has been long known that these vast accumulations of frozen snow are in motion, proceeding from the higher valleys of the Alps, where they are formed, to the lower, where they are gradually melted; the portion cut off or melted at the lower end being replaced by a new mass added at the upper end. In moving along, the glacier carries with it the fragments of rock which have fallen from the precipices above and formed upon it lines of deposit, to which the name of moraine has been given. M. Agassiz distinguishes three varieties,—lateral, in which the moraine borders the valley of the glacier, resting either on its surface, or between it and the

side of the valley;—medial, in which the moraine is formed of a long line of débris stretching down the course of the valley like a riband on the surface of the glacier;—terminal, in which the moraine is seen at the lower or terminal end of the glacier. These forms of gravel deposit, interesting as regards the history of the glacier itself, become still more so when they are used as a clue to the explanation of gravel deposits, now no longer connected with glaciers.

It will be readily conceived that any considerable variation in the temperature of the air must produce a similar variation in the amount of snow and ice, and consequently lead to an augmentation or to a diminution, as the case may be, in the glaciers resulting from them. Within very recent times, the variation has been towards an augmentation of cold, as shown by the inquiries of M. Venetz on the variations of the temperature of the Swiss Alps; but if compared with still more ancient epochs, the evidence is in favour of a rise of temperature. M. Venetz establishes the first of these positions by a reference to both historical monuments and documents, which prove that some of the Alpine passes, now scarcely practicable, were then the ordinary lines of communication. In the archives of the Commune de Bagnes, M. Rivaz found a record of a legal process between that commune and the commune of Liddes, relative to the possession of a forest then on the territory of Bagnes, which has since disappeared and been replaced by a glacier, now entirely cutting off the communication.

Many other examples are cited of the extension of the glaciers within the last 200 years; but it is small when compared with the vast extension they appear once to have attained. The evidence of former extension, though beyond the reach of historical records, may be found in the existence of ancient moraines; for, as M. Agassiz observes,—"we shall be forced to admit that many moraines, far distant from existing glaciers, must have been formed at the most remote periods, if not anterior to the creation of man." The careful examination of those deposits, which he thinks may

be classed with moraines, has led him to trace, assisted by other phenomena of glacial action, the former existence of glaciers in countries now far removed, by their comparatively elevated temperature, from the sphere of their production; and he has thus brought the British Islands within the range of ancient glacial action.

Such inquiries and reasonings lead to the belief that there was a period of intense cold, when ice and snow were spread over a large portion of the northern hemisphere; and if on the lands of that frozen epoch, the glacier descended, as it now does in Spitzbergen, to the sea, icebergs must have been also formed, and the sea covered with them and floating sheet ice. Glaciers were the carriers on land of those fragments which formed ancient moraines;—icebergs and floes were the carriers on sea of those vast fragments which now as 'erratics' are dotted here and there along the course of the then marine current, just as the modern floe or iceberg now leaves at the bottom of the ocean, where it grounds and melts, the fragments of rocks it has carried along with it. This period of intense cold is called by Geologists the glacial epoch, and it is very remarkable that no traces of glacial action have as yet been found in the earlier strata.

It is thus that the Geologist, in endeavouring to trace out the sequence of stratified deposits, has been led to discover and examine the various changes which the earth's crust has undergone at successive epochs. He has seen sea and land alternately rising and sinking before him; and standing, as it were, unmoved on a rock, he has watched and recorded the effects of each movement as it rose and fell. He is now, therefore, in a condition to compare together all the results he has observed, and to frame a system which shall combine the mineral and the organic histories of the earth's changes, so far as respects the strata of deposition: but in the progress of this investigation he has also met with rocks at each epoch of deposit which he has recognized as volcanic products; others again which, crystalline and massive, have evidently undergone

igneous fusion, and yet do no not resemble volcanic rocks; and others which, though crystalline, are as regularly stratified as sandstones and shales. These rocks will be considered in the next chapter.

Fig. 13.

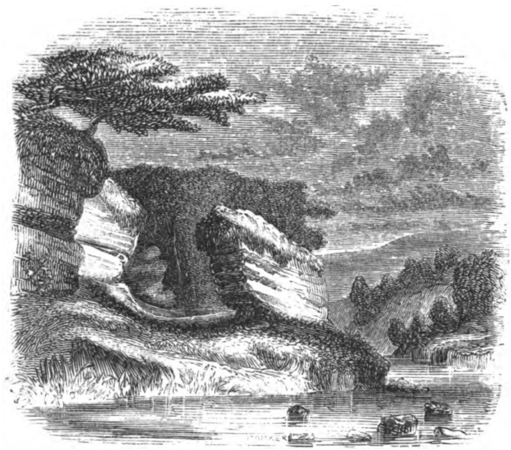


Fig. 14.

CHAPTER IV.

Plutonic, Metamorphic, and Volcanic Rocks—Elevating Forces—Dykes—Veins.

ALTHOUGH the rocks which are the subject of this chapter have in part been mentioned before, and the theory of their formation alluded to, it is necessary that the Geological Student should be made more fully acquainted with their nature, and with the circumstances connected with their production.

FIRST GROUP.

The most remarkable group of these rocks may be classed as felspathic in one family with the rock so well known by the name of granite, felspar being a constituent common to them and it.

Granite, common.—Felspar, quartz, and mica, disseminated in nearly equal proportions; the felspar lamellar, and the texture often granular. Tourmaline and hornblende are frequently accessory ingredients, and many other minerals occur occasionally, either disseminated in the mass or in veins: colour, either greyish or reddish, depending materially on the colour of the felspar.

Granite, porphyritic.—Crystals of felspar in a small-grained granite. It is sometimes difficult to separate this rock from some varieties of protogyne.

Granites are divided by joints or planes of cleavage into irregular polyhedral masses. The metals which occur in these rocks, either disseminated or in veins, are principally tin, uranium, gold, silver, and its sulphuret, oxydulous iron, bismuth, &c.

Protogyne, green.—Felspar, grey and red,—talc or chlorite of a deep green: green is the predominant colour.

Protogyne, red.—Felspar, grey or red,—talc and steatite, reddish brown or green, the red prevailing.

The protogynes exhibit the appearance of bedding on a grand scale more decidedly than granites; they form the mass of the highest rocks of the Alps.

Syenite.—Felspar, quartz, hornblende; the felspar lamellar, and often predominating. This rock has been subdivided into sections, such as granitoid, where mica occurs in small quantity; porphyritic, where large crystals of felspar are imbedded in a small-grained syenite; zirconian, hyperstenic, diallagic, according as one or other of the minerals zircon, hyperstene, diallage, replaces in whole or in part either the hornblende or the quartz. Some of the varieties, and particularly the schistoid, closely approximate the granites to the greenstones, and some of them are very similar to metamorphic rocks.

Pegmatite.—Felspar and quartz,—the felspar lamellar, and the quartz often arranged in broken lines. The principal variety of this species is the well-known graphic granite in which the broken lines of the quartz imitate Hebrew characters.

The quartz sometimes occurs in grains, and by the introduction of mica, the rock passes into granite or gneiss. The colour of the felspar gives it occasionally a brown or brownish red hue. The finest kaolins, or porcelain clays, proceed from the decomposition of the graphic and granular pegmatites.

SECOND GROUP.

In this may be classed another extensive family of rocks, well known in some varieties as greenstone, the predominant constituent being hornblende.

Hornblende Rock.—Base, hornblende with mica, felspar, garnets, &c. Texture lamellar, and structure sometimes massive, sometimes fissile.

There are many varieties of this rock, such as the granitoid, the serpentine, the micaceous, the schistoid, &c., so named from the peculiar mineral or structure which prevails; and it

is thus that the rock assumes by turns the true character of a plutonic rock, or those of the metamorphic series.

Greenstone (*Diorite, &c.*)—Hornblende and compact felspar, nearly equally disseminated. This rock is also subject to numerous variations, becoming granitoid, schistose, porphyritic, &c. The orbicular granite of Corsica is a greenstone in which spheroidal masses of hornblende and felspar occur in a paste of granular greenstone: a similar rock occurs in America, in which the spheroids are very small.

In the pyromeride, or orbicular porphyry of Corsica, radiated spheroids occur in a paste of compact felspar and quartz. Such forms are very interesting, as they are examples of concretionary structure, or of a tendency to definite arrangement within a mass.

The eurites, or felspar rocks and felspar porphyries, will be considered with volcanic rocks, though they sometimes approximate closely to the granitic type.

The metamorphic rocks constitute the next class, which will be now noticed, as in many respects they approach very closely to the plutonic. In them a schistose and stratified character becomes apparent, whilst a highly crystalline structure prevails in several of the divisions. For a long time the term primary rocks included both granites and crystalline schists; and after the igneous theory of formation had been admitted for the massive rocks, it still seemed difficult to separate from them a rock so highly crystalline as gneiss, and which is also composed of felspar, quartz, and mica. The alternation of different species of rocks, such as gneiss, mica slate, granular limestone, clay slate under all the forms of a definite stratification, rendered it necessary to adopt some other theory than that which would have represented such rocks as successive layers of the original crust of the earth. Had they been all homogeneous, or all similar in constitution to either granites or greenstones, such an explanation might have been admitted, but it was insufficient to account for layers of limestone of

various thicknesses interstratified with gneiss or mica slate. The reasoning therefore which has been applied to other stratified rocks must be adopted with these; and they must be viewed as ancient sedimentary deposits, on which some peculiar change has been effected, so as to conceal entirely their original condition. This change, which is signified by the expressive term metamorphous or metamorphic, is, however, to a certain extent not peculiar to such rocks; as many of the sandstones, conglomerates, and limestones have also undergone a change from the loose muddy paste in which they were originally deposited. The description may be commenced by the rock nearest in character to granite.

Gneiss.—Felspar, mica, and quartz,—the felspar lamellar, and the mica abundant, arranged in lines so as to produce a lamellar or schistose structure.

The varieties of this rock are numerous, as it is sometimes a distinct granite in texture, and sometimes merges into the next species, mica schist. It is occasionally talcose, approximating to protogyne,—sometimes porphyritic, and occasionally loses its quartz,—whilst in a rare variety graphite in scales replaces the mica; and it will readily be imagined how difficult in some cases it must be to draw a line of demarcation between granitic and gneissose rocks.

Mica Schist.—Glimmerschiefer of the Germans. Mica predominates, and the structure is fissile. Garnets enter as an accessory constituent into this rock, as well as several other minerals. There are many varieties, as it becomes gneissose by the introduction of felspar, granitic by a more irregular structure, porphyritic, having a scaly fracture, or merges into a clay slate: it is sometimes talcose.

Clay Slate.—In this rock the distinction of crystalline elements is lost, but there are frequently accessory crystals of quartz, felspar, &c., and it may thus be approximated to mica slate, just as that rock merges into it. It becomes sometimes so calcareous as to be almost a limestone slate, and the alternation of thin bands of limestone with the metamorphic

rocks, especially with mica slate, is a remarkable and interesting character, strongly elucidatory of their origin. Clay slate is also occasionally talcose, or becomes a talc slate.

It is not necessary to dwell particularly on some other less common rocks, such as serpentine, though they are of much practical interest. One fact will have struck the reader in respect to these rocks generally, independent of any theory connected with it; namely, that massive and metamorphic rocks appear under several distinct forms common to both; and as this fact may also be extended to volcanic rocks, it will be applied in the accompanying Table, as a ready means to make the observer familiar with such rocks; and subsequently the theory connected with these changes will be discussed.

The porphyritic character which is common both to the igneous and metamorphic rocks, and requires a brief notice, is illustrated by the researches of modern Chemists, who have succeeded in retaining stony matter in fusion under such circumstances as should lead to the ultimate formation in the mass, when cooling, of crystals. Various precious gems have thus been created in the laboratory; and to these experimental proofs of the manner in which the crystals of porphyries may have been formed, may be added the researches of Person on alloys, as he has shown that metals combined together in the due proportions may first consolidate, by arriving at a common solidifying point, into a definite alloy, and yet separate afterwards. The fact that such separation often takes place before consolidation,—the metals not arriving at a common point of solidification,—had before been noticed; and both facts, when extended to stony minerals, are highly explanatory of the porphyritic condition of rocks.

Massive Crystalline Rocks.		Stratified Crystalline Rocks, and more simple Strata connected with them.	
Granite	Felspar, quartz, mica.	Gneiss	Felspar, quartz, mica.
		Mica schist	Quartz and mica.
		Clay slate	Crystals become so small that the mass appears homogeneous, though still glistening.
Pegmatite (graphic granite)	Felspar, quartz.	. . . .	. . . .
Protogyne	Felspar, quartz, talc.	Talc gneiss	Felspar, quartz, talc.
		Talc slate	Quartz and talc.
Syenite	Felspar, quartz, hornblende.	Syenite schist	Felspar, quartz, hornblende.
Greenstone	Felspar, hornblende.	Greenstone schist	Hornblende, felspar.
		Hornblende schist	Principally hornblende.
Hypersthene rock	Felspar, hypersthene.	Hypersthene schist	Felspar, hypersthene.
Porphyry	Granites, syenites, and other massive rocks exhibit frequently a porphyritic structure by the development of isolated crystals in the mass.	Hornstone porphyry Felspar porphyry Clay porphyry	(The preceding rocks, including the various crystalline schists and many others, exhibit occasionally the porphyritic character.)
Ophite	Porphyritic serpentine or green porphyry.		
Dolerite (basaltic greenstone)	Felspar, augite. The crystals distinct, closely associated with ordinary basalt.	. . . .	Looking at the character of some of the beds associated with the basalt, it is scarcely possible to doubt that many of them are metamorphic, over which at various epochs the basalt has flown, and that similar changes have taken place in them as in other metamorphic strata. Using them as an illustration of the crystalline schists, it may also be suspected that streams of still more ancient lava exist in the close-grained greenstones associated in regular stratification with them.
Melaphyr, or augite porphyry	Felspar, augite. Rendered porphyritic by isolated crystals of both felspar and augite.	. . . .	This rock also indicates in part an original schistose arrangement.
Trachyte, or trapp porphyry	Felspar base, with crystals of glassy felspar; the ancient lava of Auvergne and of the Rhine.	. . . .	As yet I am not aware of any detailed account of truly metamorphic rocks connected with these.
Andesite	So called from the Andes. The trachytes occur also in the basaltic district of Ireland, so that these two forms of lava are associated together just as the most recent lavas and basalt are.		
Domite	More earthy trachyte.		
Basalt	Felspar, augite. The mixture so intimate that the separate crystals can scarcely be distinguished: a distinctly volcanic product, still occurring in recent lavas.		
Lava, modern	Including basalts similar to those of more ancient volcanoes.		
Leucite lava	Leucite and augite—the former prevailing; this mixture being also rendered porphyritic by isolated crystals of augite and glassy felspar.		

Before proceeding to the truly volcanic rocks, beginning with basalt, it will be well to examine more closely the connection of the plutonic and metamorphic rocks with the leading physical phenomena of the universe. Astronomy teaches the great probability that the now solid planetary bodies were once in a state of gaseous fusion as nebulous matter, and the earth itself affords much confirmatory proof of the fact. Its figure is that of an oblate spheroid, which a liquid body exposed to the conjoint action of gravity and a rotatory impulse would assume: in such figure, then, there is primary evidence of its original fluidity. That the cause of that original fluidity was heat, is gathered from an examination of the temperature of the earth's crust at various depths, as it is thereby established that the temperature below the cooled surface increases on descending, and that at great depths there is still existing a vast reservoir of central heat. From numerous observations made in mines and by Artesian wells in France, England, Prussia, Russia, and elsewhere, Leonhard states that the temperature increases by 1° Reaumur, or $2\frac{1}{4}$° Fahrenheit, in 120 feet. M. Reich considers the temperature in the mines of Saxony to increase 1° centigrade in 41·84 m. of depth, or $1\frac{4}{5}$° Fahrenheit, in 135 feet. In a boring in the Military School at Paris, the increase was found to be 1° centigrade, or $1\frac{4}{5}$° Fahrenheit, for about 96 feet. In Mr. Fox's experiments in Cornwall, the increase was found to be about 1° in 47′: in those of Mr. Oldham, in the copper mines of Knockmahon, county of Waterford, 1° in 82′, being a lower rate of increase than that of previous inquirers. It may be therefore assumed as a reasonable approximation, though subject to many variations from the different conducting powers of different strata, that the temperature increases 1° Fahrenheit in 60 feet of depth; and if the rate of increase were considered constant, there would, at 60,000 feet, be a temperature of 1000° or that of low red heat; but as the temperature will increase with the depth in an augmenting ratio, Leonhard assumes that this temperature would be attained at about 35,000 feet, being a

depth only double the height of Cotopaxi, the most remarkable of the Peruvian volcanoes. Descending still lower, the temperature, at a very moderate depth compared with the magnitude of the earth, would be found sufficient to retain mineral matter in a state of fusion; and it is therefore unnecessary to place at a great depth the source of the lava which is still pouring out in so many parts of the earth. The similarity of lava, wherever found, and the close agreement as to composition and physical characters of the basalt of ancient epochs and of that still bursting through and intersecting the walls of modern volcanoes, are further proofs that a common origin must be ascribed to all such eruptions, which are due, as well as the accompanying physical phenomena of earthquakes, to forces acting on the still liquid portion of the earth.

Admitting then the original igneous fluidity of the earth, and its gradual cooling from the crust downwards, it has been demonstrated by Fourier—

1. That the cooling of the earth, and the increase of temperature in proportion to the depth below the surface, has been much greater formerly than it now is.

2. That more than 30,000 years will be required to lessen, by one-half, the present rate of increase of temperature; that is, to reduce the increase to $\frac{1}{2}°$ in 60 feet.

3. That the effect of central heat is now scarcely perceptible on the surface, not raising the thermometer $\frac{1}{17}°$.

4. That for nearly 2000 years this effect has not diminished by $\frac{1}{20}°$, and that in this, as in all the great phenomena of the universe, a marked character of stability is perceptible.

The density of the earth affords another means of judging of its internal condition. It has been stated that the density of the crust lies between 2·7 and 2·9; but the density of the whole earth, derived from pendulum experiments, of which more will be said when treating of elevatory forces, is about 5·5; so that it is evident that the ponderable matter of the interior of the earth is very much denser than the matter of

the crust, which is quite consistent with the previous supposition of original fluidity; for though gases mutually permeate each other and diffuse themselves, liquids, when they do not exercise a chemical action on each other, obey the ordinary laws of gravity, and arrange themselves in the order of their density. The density of basalt does not usually exceed 3·1, so that the difference observable by the Geologist in the densities of rocks is very small. The radius of the earth is 3908 miles; but if we suppose it 4000 miles, and divide it into 10 equal parts, and then assume that in descending the density increases in an arithmetical progression by about 1·5 for each part, the problem will be thus stated: the average density in the first annular space of 400 miles will be 2·7; in the second 4·2, and so on,—the density of the last 400 miles being about 16·2; and this view of the case does not appear inconsistent with the real facts, as it allows for every 100 miles an increase in density of ·3, and, as before observed, this is probably more than the thickness of consolidated strata.

The increasing density of the earth, from the surface to the centre, is useful in forming an opinion of the true nature of plutonic rocks. The density of none of the true granites equals that of basalt, and it rarely exceeds 2·6, so that it is highly improbable that granite has proceeded from a deep-seated source. Granite does not throw out dykes either cutting through the strata or filling up cracks produced by fracture in them; its veins are principally confined to the metamorphic rocks, and it does not exhibit lava currents: it may therefore be considered a lower portion of the immediate crust of the earth which has been liquefied and forced to the surface at various epochs, but has not been erupted. The full development of crystals in these rocks requires indeed slow cooling but not great pressure, and there is therefore no reason for supposing that they were ever far below the surface.

In extending the inquiry to the crystalline schists, it will be naturally asked whether any portion of them may be con-

sidered a part of the crust of the earth in the actual state in which it was at first cooled down and consolidated. The alternation of limestone and of micaceous beds with the more crystalline layers confines this question within very narrow limits, and if any rocks are visible which have escaped the modifying action of water, air, and heat, it is probable that they are only such rocks as the highly inclined and distinctly bedded varieties of protogyne which occur in the Alps, —being neither distinctly massive nor distinctly stratified. There is a similar difficulty in determining whether the hornblendic rocks associated with the crystalline schists are also truly metamorphic, or volcanic rocks erupted amongst them. Their density, approximating closely to that of basalts, may lead to the belief that they were erupted rocks; and modern Geologists have discovered so strong a resemblance between some of the strata associated with the crystalline schists and the ashes, lapilli, &c., of volcanoes, as to add confirmation to the belief that lava currents have contributed with internal heat to the production of the metamorphic strata. This portion, therefore, of the Earth's Mineral History forms a consistent introduction to the next, in which the products of volcanic eruptions are no longer doubtful, being similar to and even identical with the mineral matter erupted from volcanoes either actually existing or distinctly recognized as having existed since the earth's surface had assumed its present form. The truly volcanic rocks have been divided into three sections, —the trachytic, the basaltic, and the lavic; the last alone being now observable as a volcanic erupted substance, though dykes of basalt penetrate the walls of volcanic cones.

The trachytes are felspathic rocks, consisting of a highly crystalline paste of compact felspar, with crystals of augite and other minerals disseminated in the mass. Domite, porphyritic eurite, pumite, phonolite or clinkstone, belong to the division; and there is also a trachytic breccia where mechanical action has assisted in the production of the result. They are found as well in countries where volcanoes are still in

action as in those where they have become extinct, and there seems sufficient proof that their source was immediately below the granitic crust. Though generally but little spread over the old continents, they occur in the chain of the Caucasus, in Hungary, Transylvania, Auvergne, Isles of Greece, Italy, &c., and in comparatively small quantity in the counties of Antrim and Down in Ireland; but they acquire an enormous development in South America, in the chain of the Andes of which they form the summits, the beds being sometimes 14,000 or even 18,000 feet thick, as at Chimborazo and the volcano Guagua-Pichincha. The trachytes are sometimes covered by tertiary strata, but never by the secondary or older strata, and it has therefore been assumed that the epoch of their appearance is that of the earlier tertiaries. In Auvergne they often form the boundaries of ancient and partially destroyed volcanic vents; and it is not improbable that in like manner, in Ireland, the Antrim and Down trachytes are portions of the boundary of some great volcanic vent which may have occupied the site of the present Lough Neagh, and through which much of the basalt may have been poured out.

The basaltic rocks are characterized by the great quantity of augite which prevails over the felspar, so as to render them augitic rather than felspathic rocks. Basalt has a considerable density, ranging to 3·3 in the more highly augitic varieties; it cuts through granite and every successive rock, carrying with it and enveloping fragments of the rocks broken through. The remarkable lines of this igneous matter, which may be sometimes traced for very long distances, are called dykes, and, when exposed by the decomposition of the softer strata through which they have passed, stand out as walls, whence they have derived their name. See fig. 15, which is the celebrated dyke called Lady O'Cane's Bridge, and fig. 16, which represents another view of it.

Protogyne, red.—Felspar, grey or red,—talc and steatite, reddish brown or green, the red prevailing.

The protogynes exhibit the appearance of bedding on a grand scale more decidedly than granites; they form the mass of the highest rocks of the Alps.

Syenite.—Felspar, quartz, hornblende; the felspar lamellar, and often predominating. This rock has been subdivided into sections, such as granitoid, where mica occurs in small quantity; porphyritic, where large crystals of felspar are imbedded in a small-grained syenite; zirconian, hyperstenic, diallagic, according as one or other of the minerals zircon, hyperstene, diallage, replaces in whole or in part either the hornblende or the quartz. Some of the varieties, and particularly the schistoid, closely approximate the granites to the greenstones, and some of them are very similar to metamorphic rocks.

Pegmatite.—Felspar and quartz,—the felspar lamellar, and the quartz often arranged in broken lines. The principal variety of this species is the well-known graphic granite in which the broken lines of the quartz imitate Hebrew characters.

The quartz sometimes occurs in grains, and by the introduction of mica, the rock passes into granite or gneiss. The colour of the felspar gives it occasionally a brown or brownish red hue. The finest kaolins, or porcelain clays, proceed from the decomposition of the graphic and granular pegmatites.

SECOND GROUP.

In this may be classed another extensive family of rocks, well known in some varieties as greenstone, the predominant constituent being hornblende.

Hornblende Rock.—Base, hornblende with mica, felspar, garnets, &c. Texture lamellar, and structure sometimes massive, sometimes fissile.

There are many varieties of this rock, such as the granitoid, the serpentine, the micaceous, the schistoid, &c., so named from the peculiar mineral or structure which prevails; and it

is thus that the rock assumes by turns the true character of a plutonic rock, or those of the metamorphic series.

Greenstone (*Diorite, &c.*)—Hornblende and compact felspar, nearly equally disseminated. This rock is also subject to numerous variations, becoming granitoid, schistose, porphyritic, &c. The orbicular granite of Corsica is a greenstone in which spheroidal masses of hornblende and felspar occur in a paste of granular greenstone: a similar rock occurs in America, in which the spheroids are very small.

In the pyromeride, or orbicular porphyry of Corsica, radiated spheroids occur in a paste of compact felspar and quartz. Such forms are very interesting, as they are examples of concretionary structure, or of a tendency to definite arrangement within a mass.

The eurites, or felspar rocks and felspar porphyries, will be considered with volcanic rocks, though they sometimes approximate closely to the granitic type.

The metamorphic rocks constitute the next class, which will be now noticed, as in many respects they approach very closely to the plutonic. In them a schistose and stratified character becomes apparent, whilst a highly crystalline structure prevails in several of the divisions. For a long time the term primary rocks included both granites and crystalline schists; and after the igneous theory of formation had been admitted for the massive rocks, it still seemed difficult to separate from them a rock so highly crystalline as gneiss, and which is also composed of felspar, quartz, and mica. The alternation of different species of rocks, such as gneiss, mica slate, granular limestone, clay slate under all the forms of a definite stratification, rendered it necessary to adopt some other theory than that which would have represented such rocks as successive layers of the original crust of the earth. Had they been all homogeneous, or all similar in constitution to either granites or greenstones, such an explanation might have been admitted, but it was insufficient to account for layers of limestone of

various thicknesses interstratified with gneiss or mica slate. The reasoning therefore which has been applied to other stratified rocks must be adopted with these; and they must be viewed as ancient sedimentary deposits, on which some peculiar change has been effected, so as to conceal entirely their original condition. This change, which is signified by the expressive term metamorphous or metamorphic, is, however, to a certain extent not peculiar to such rocks; as many of the sandstones, conglomerates, and limestones have also undergone a change from the loose muddy paste in which they were originally deposited. The description may be commenced by the rock nearest in character to granite.

Gneiss.—Felspar, mica, and quartz,—the felspar lamellar, and the mica abundant, arranged in lines so as to produce a lamellar or schistose structure.

The varieties of this rock are numerous, as it is sometimes a distinct granite in texture, and sometimes merges into the next species, mica schist. It is occasionally talcose, approximating to protogyne,—sometimes porphyritic, and occasionally loses its quartz,—whilst in a rare variety graphite in scales replaces the mica; and it will readily be imagined how difficult in some cases it must be to draw a line of demarcation between granitic and gneissose rocks.

Mica Schist.—Glimmerschiefer of the Germans. Mica predominates, and the structure is fissile. Garnets enter as an accessory constituent into this rock, as well as several other minerals. There are many varieties, as it becomes gneissose by the introduction of felspar, granitic by a more irregular structure, porphyritic, having a scaly fracture, or merges into a clay slate: it is sometimes talcose.

Clay Slate.—In this rock the distinction of crystalline elements is lost, but there are frequently accessory crystals of quartz, felspar, &c., and it may thus be approximated to mica slate, just as that rock merges into it. It becomes sometimes so calcareous as to be almost a limestone slate, and the alternation of thin bands of limestone with the metamorphic

rocks, especially with mica slate, is a remarkable and interesting character, strongly elucidatory of their origin. Clay slate is also occasionally talcose, or becomes a talc slate.

It is not necessary to dwell particularly on some other less common rocks, such as serpentine, though they are of much practical interest. One fact will have struck the reader in respect to these rocks generally, independent of any theory connected with it; namely, that massive and metamorphic rocks appear under several distinct forms common to both; and as this fact may also be extended to volcanic rocks, it will be applied in the accompanying Table, as a ready means to make the observer familiar with such rocks; and subsequently the theory connected with these changes will be discussed.

The porphyritic character which is common both to the igneous and metamorphic rocks, and requires a brief notice, is illustrated by the researches of modern Chemists, who have succeeded in retaining stony matter in fusion under such circumstances as should lead to the ultimate formation in the mass, when cooling, of crystals. Various precious gems have thus been created in the laboratory; and to these experimental proofs of the manner in which the crystals of porphyries may have been formed, may be added the researches of Person on alloys, as he has shown that metals combined together in the due proportions may first consolidate, by arriving at a common solidifying point, into a definite alloy, and yet separate afterwards. The fact that such separation often takes place before consolidation,—the metals not arriving at a common point of solidification,—had before been noticed; and both facts, when extended to stony minerals, are highly explanatory of the porphyritic condition of rocks.

Massive Crystalline Rocks.		Stratified Crystalline Rocks, and more simple Strata connected with them.	
Granite	Felspar, quartz, mica.	Gneiss Mica schist Clay slate	Felspar, quartz, mica. Quartz and mica. Crystals become so small that the mass appears homogeneous, though still glistening.
Pegmatite (graphic granite)	Felspar, quartz.	. . . .	. . . .
Protogyne	Felspar, quartz, talc.	Talc gneiss Talc slate	Felspar, quartz, talc. Quartz and talc.
Syenite	Felspar, quartz, hornblende.	Syenite schist	Felspar, quartz, hornblende.
Greenstone	Felspar, hornblende.	Greenstone schist Hornblende schist	Hornblende, felspar. Principally hornblende.
Hypersthene rock	Felspar, hypersthene.	Hypersthene schist	Felspar, hypersthene.
Porphyry	Granites, syenites, and other massive rocks exhibit frequently a porphyritic structure by the development of isolated crystals in the mass.	Hornstone porphyry Felspar porphyry Clay porphyry	(The preceding rocks, including the various crystalline schists and many others, exhibit occasionally the porphyritic character.)
Ophite	Porphyritic serpentine or green porphyry.		
Dolerite (basaltic greenstone)	Felspar, augite. The crystals distinct, closely associated with ordinary basalt.	. . . .	Looking at the character of some of the beds associated with the basalt, it is scarcely possible to doubt that many of them are metamorphic, over which at various epochs the basalt has flown, and that similar changes have taken place in them as in other metamorphic strata. Using them as an illustration of the crystalline schists, it may also be suspected that streams of still more ancient lava exist in the close-grained greenstones associated in regular stratification with them.
Melaphyr, or augite porphyry	Felspar, augite. Rendered porphyritic by isolated crystals of both felspar and augite.	. . . .	This rock also indicates in part an original schistose arrangement.
Trachyte, or trapp porphyry	Felspar base, with crystals of glassy felspar; the ancient lava of Auvergne and of the Rhine.	. . . .	As yet I am not aware of any detailed account of truly metamorphic rocks connected with these.
Andesite	So called from the Andes. The trachytes occur also in the basaltic district of Ireland, so that these two forms of lava are associated together just as the most recent lavas and basalt are.		
Domite	More earthy trachyte.		
Basalt	Felspar, augite. The mixture so intimate that the separate crystals can scarcely be distinguished: a distinctly volcanic product, still occurring in recent lavas.		
Lava, modern	Including basalts similar to those of more ancient volcanoes.		
Leucite lava	Leucite and augite—the former prevailing; this mixture being also rendered porphyritic by isolated crystals of augite and glassy felspar.		

Before proceeding to the truly volcanic rocks, beginning with basalt, it will be well to examine more closely the connection of the plutonic and metamorphic rocks with the leading physical phenomena of the universe. Astronomy teaches the great probability that the now solid planetary bodies were once in a state of gaseous fusion as nebulous matter, and the earth itself affords much confirmatory proof of the fact. Its figure is that of an oblate spheroid, which a liquid body exposed to the conjoint action of gravity and a rotatory impulse would assume: in such figure, then, there is primary evidence of its original fluidity. That the cause of that original fluidity was heat, is gathered from an examination of the temperature of the earth's crust at various depths, as it is thereby established that the temperature below the cooled surface increases on descending, and that at great depths there is still existing a vast reservoir of central heat. From numerous observations made in mines and by Artesian wells in France, England, Prussia, Russia, and elsewhere, Leonhard states that the temperature increases by 1° Reaumur, or $2\frac{1}{4}$° Fahrenheit, in 120 feet. M. Reich considers the temperature in the mines of Saxony to increase 1° centigrade in 41·84 m. of depth, or $1\frac{4}{5}$° Fahrenheit, in 135 feet. In a boring in the Military School at Paris, the increase was found to be 1° centigrade, or $1\frac{4}{5}$° Fahrenheit, for about 96 feet. In Mr. Fox's experiments in Cornwall, the increase was found to be about 1° in 47′: in those of Mr. Oldham, in the copper mines of Knockmahon, county of Waterford, 1° in 82′, being a lower rate of increase than that of previous inquirers. It may be therefore assumed as a reasonable approximation, though subject to many variations from the different conducting powers of different strata, that the temperature increases 1° Fahrenheit in 60 feet of depth; and if the rate of increase were considered constant, there would, at 60,000 feet, be a temperature of 1000° or that of low red heat; but as the temperature will increase with the depth in an augmenting ratio, Leonhard assumes that this temperature would be attained at about 35,000 feet, being a

depth only double the height of Cotopaxi, the most remarkable of the Peruvian volcanoes. Descending still lower, the temperature, at a very moderate depth compared with the magnitude of the earth, would be found sufficient to retain mineral matter in a state of fusion; and it is therefore unnecessary to place at a great depth the source of the lava which is still pouring out in so many parts of the earth. The similarity of lava, wherever found, and the close agreement as to composition and physical characters of the basalt of ancient epochs and of that still bursting through and intersecting the walls of modern volcanoes, are further proofs that a common origin must be ascribed to all such eruptions, which are due, as well as the accompanying physical phenomena of earthquakes, to forces acting on the still liquid portion of the earth.

Admitting then the original igneous fluidity of the earth, and its gradual cooling from the crust downwards, it has been demonstrated by Fourier—

1. That the cooling of the earth, and the increase of temperature in proportion to the depth below the surface, has been much greater formerly than it now is.

2. That more than 30,000 years will be required to lessen, by one-half, the present rate of increase of temperature; that is, to reduce the increase to $\frac{1}{2}°$ in 60 feet.

3. That the effect of central heat is now scarcely perceptible on the surface, not raising the thermometer $\frac{1}{17}°$.

4. That for nearly 2000 years this effect has not diminished by $\frac{1}{20}°$, and that in this, as in all the great phenomena of the universe, a marked character of stability is perceptible.

The density of the earth affords another means of judging of its internal condition. It has been stated that the density of the crust lies between 2·7 and 2·9; but the density of the whole earth, derived from pendulum experiments, of which more will be said when treating of elevatory forces, is about 5·5; so that it is evident that the ponderable matter of the interior of the earth is very much denser than the matter of

the crust, which is quite consistent with the previous supposition of original fluidity; for though gases mutually permeate each other and diffuse themselves, liquids, when they do not exercise a chemical action on each other, obey the ordinary laws of gravity, and arrange themselves in the order of their density. The density of basalt does not usually exceed 3·1, so that the difference observable by the Geologist in the densities of rocks is very small. The radius of the earth is 3908 miles; but if we suppose it 4000 miles, and divide it into 10 equal parts, and then assume that in descending the density increases in an arithmetical progression by about 1·5 for each part, the problem will be thus stated: the average density in the first annular space of 400 miles will be 2·7; in the second 4·2, and so on,—the density of the last 400 miles being about 16·2; and this view of the case does not appear inconsistent with the real facts, as it allows for every 100 miles an increase in density of ·3, and, as before observed, this is probably more than the thickness of consolidated strata.

The increasing density of the earth, from the surface to the centre, is useful in forming an opinion of the true nature of plutonic rocks. The density of none of the true granites equals that of basalt, and it rarely exceeds 2·6, so that it is highly improbable that granite has proceeded from a deep-seated source. Granite does not throw out dykes either cutting through the strata or filling up cracks produced by fracture in them; its veins are principally confined to the metamorphic rocks, and it does not exhibit lava currents: it may therefore be considered a lower portion of the immediate crust of the earth which has been liquefied and forced to the surface at various epochs, but has not been erupted. The full development of crystals in these rocks requires indeed slow cooling but not great pressure, and there is therefore no reason for supposing that they were ever far below the surface.

In extending the inquiry to the crystalline schists, it will be naturally asked whether any portion of them may be con-

sidered a part of the crust of the earth in the actual state in which it was at first cooled down and consolidated. The alternation of limestone and of micaceous beds with the more crystalline layers confines this question within very narrow limits, and if any rocks are visible which have escaped the modifying action of water, air, and heat, it is probable that they are only such rocks as the highly inclined and distinctly bedded varieties of protogyne which occur in the Alps, —being neither distinctly massive nor distinctly stratified. There is a similar difficulty in determining whether the hornblendic rocks associated with the crystalline schists are also truly metamorphic, or volcanic rocks erupted amongst them. Their density, approximating closely to that of basalts, may lead to the belief that they were erupted rocks; and modern Geologists have discovered so strong a resemblance between some of the strata associated with the crystalline schists and the ashes, lapilli, &c., of volcanoes, as to add confirmation to the belief that lava currents have contributed with internal heat to the production of the metamorphic strata. This portion, therefore, of the Earth's Mineral History forms a consistent introduction to the next, in which the products of volcanic eruptions are no longer doubtful, being similar to and even identical with the mineral matter erupted from volcanoes either actually existing or distinctly recognized as having existed since the earth's surface had assumed its present form. The truly volcanic rocks have been divided into three sections, —the trachytic, the basaltic, and the lavic; the last alone being now observable as a volcanic erupted substance, though dykes of basalt penetrate the walls of volcanic cones.

The trachytes are felspathic rocks, consisting of a highly crystalline paste of compact felspar, with crystals of augite and other minerals disseminated in the mass. Domite, porphyritic eurite, pumite, phonolite or clinkstone, belong to the division; and there is also a trachytic breccia where mechanical action has assisted in the production of the result. They are found as well in countries where volcanoes are still in

action as in those where they have become extinct, and there seems sufficient proof that their source was immediately below the granitic crust. Though generally but little spread over the old continents, they occur in the chain of the Caucasus, in Hungary, Transylvania, Auvergne, Isles of Greece, Italy, &c., and in comparatively small quantity in the counties of Antrim and Down in Ireland; but they acquire an enormous development in South America, in the chain of the Andes of which they form the summits, the beds being sometimes 14,000 or even 18,000 feet thick, as at Chimborazo and the volcano Guagua-Pichincha. The trachytes are sometimes covered by tertiary strata, but never by the secondary or older strata, and it has therefore been assumed that the epoch of their appearance is that of the earlier tertiaries. In Auvergne they often form the boundaries of ancient and partially destroyed volcanic vents; and it is not improbable that in like manner, in Ireland, the Antrim and Down trachytes are portions of the boundary of some great volcanic vent which may have occupied the site of the present Lough Neagh, and through which much of the basalt may have been poured out.

The basaltic rocks are characterized by the great quantity of augite which prevails over the felspar, so as to render them augitic rather than felspathic rocks. Basalt has a considerable density, ranging to 3·3 in the more highly augitic varieties; it cuts through granite and every successive rock, carrying with it and enveloping fragments of the rocks broken through. The remarkable lines of this igneous matter, which may be sometimes traced for very long distances, are called dykes, and, when exposed by the decomposition of the softer strata through which they have passed, stand out as walls, whence they have derived their name. See fig. 15, which is the celebrated dyke called Lady O'Cane's Bridge, and fig. 16, which represents another view of it.

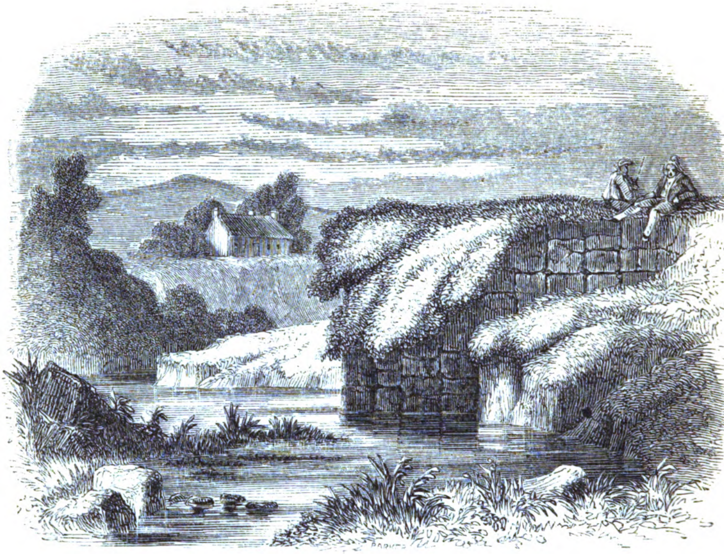


Fig. 15.—East View.

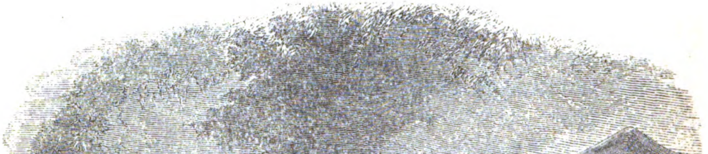


Fig. 16.—West View.

The reasoning already applied to granite, together with the fact of its penetration by basalt, leaves no doubt that the latter has come from depths below the granite and metamorphic schists, and at various epochs, but at the same time shows that there is no reason for believing it to have come from a depth exceeding 100 miles. Basalt is rarely found near the summits of volcanoes, but is usually at their base or surrounds them, and is evidently anterior to the lava currents which overlie it: it is very extensively developed in the vicinity of extinct volcanoes, and is justly considered a truly volcanic rock.

In many countries, and especially in Ireland and Scotland, basalt is spread out in extensive plains or beds, divided in section or depth into many successive layers, some globular and some columnar in structure, with beds of ochre or ferruginous scoria separating them. Sometimes, as in the vicinity of Jorullo, in Mexico, the basalt has been puffed up by the elastic gases below into small cones or bosses, which, having been subsequently cracked, emit aqueous and sulphurous vapours. These Homitos, as they are called, cover in thousands the great plain of Mal-Pais, in which Jorullo rises, so that the surface resembles the bubbles on the top of a boiling pasty or viscous fluid. In 1780 the heat of the homitos was so great that a cigar could be lighted by plunging it 2 or 3 inches into one of the lateral cracks. It has been stated that layers of ochreous scoria divide the mass of basalt into several successive flows, and seem to indicate that it had flowed over dry ground, and not, as often supposed, under water; and the connection of irregular or orbicularly crystallized basalt with columnar, the former being on the top of the latter, is another proof of this fact, as it doubtless results from the more rapid flowing and cooling of the upper portion. A beautiful example of this effect is exhibited at Craignahulliar, in the county of Antrim. See fig. 17.

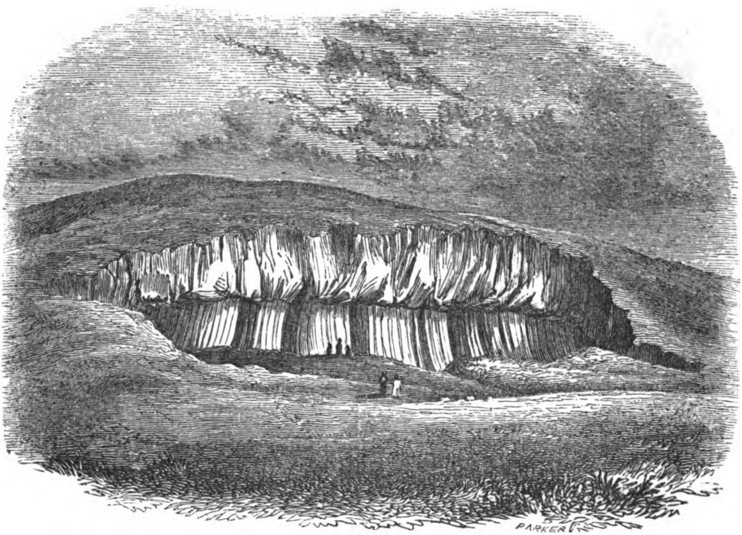


Fig. 17.

As before remarked, it is not improbable that some of the beds associated with the basaltic mass are really sedimentary deposits which have undergone a metamorphic change during, and partly consequent upon, the basaltic eruptions.

The lavic division can be studied in the phenomena of still active volcanoes. As the basalt was posterior in its appearance to trachytes, so the true lavas have been erupted subsequently to the basalts. The lava of extinct volcanoes approaches more closely to trachytes, being felspathic, whereas that of existing volcanoes, being augitic, is nearer to basalts. Here also successive flows are frequently separated by beds of ashes, scoria, lapilli, &c., as may be seen in the vicinity of Vesuvius. The celebrated eruption, supposed to be the first of Vesuvius, which in the year 79 destroyed the cities of Herculaneum, Pompeii, and Stabiæ, and caused the death of the elder Pliny, consisted of ashes. It would be impossible, in the limited space of this volume, to describe all the remarkable

phenomena of volcanoes; but as they are closely connected with the forces which produce earthquakes and elevations of the strata, it is right to notice the great number actually known, namely, at least 303, as exhibited in the following Table from Girardin, which, however, must be considered only approximative.

Portions of the Earth.	On Continents.	In Islands.	Total.
Europe . . .	4	20	24
Africa . . .	2	9	11
Asia	17	29	46
America . .	86	28	114
Oceania . .	"	108	108
Total . . .	109	194	303

And in respect to extinct volcanoes, though there are not sufficient data to state the exact number, they must have been very numerous, so that the eruptive forces were then at least equal, and probably even exceeding in intensity their present energy, so far as the quantity of matter erupted.

The practical importance of the rocks which have been thus passed in review requires also a brief notice. In those which are more or less metamorphic, the varieties of clay slate, called roofing slate, are found; and this physical condition is therefore a guide in searching for them, as their peculiarities and value are due to metamorphic action. The lesser cleavage of the slate is usually transverse to the dip of the beds; and the probable value of the slaty beds may be estimated by the presence or absence of this character, as the planes of separation by cleavage are more regular, and possess a more even surface than those of stratification. For flagging, many crystalline schists are excellent, the surface of stratification being sufficiently even, especially in the gneisose varieties of mica slate, and even in gneiss itself; and they are also often excellent for rough buildings, affording a flat bedding and a very durable composition. In these three varieties of metamorphic schists there is a remarkable correspondence in the

important physical character of specific gravity, the range in each being from about 2·6 to 3·1, the latter being the specific gravity of the more dense or indurated varieties, which frequently become hornblendic or greenstone schists. As road stones, only the latter should be used, as the other varieties speedily break up and are reduced to mud. Roofing slates ought to split thin and even, should not readily cleave into fragments, should not absorb much water, which causes them to become speedily disfigured with moss, and induces damp; and they should not be scaly. Though the dark grey varieties are most approved, the silver grey are usually the most durable. Some varieties of mica slate afford good roofing slates, which are, however, seldom so thin and even as the less crystalline schists. The most important locality in the United Kingdom is Wales; but there are also very good slates in the South-west and in the South of Ireland, as in the island of Valentia, and some in the mica slate of the North of Ireland, though the latter are not equal to the true slates. Of foreign localities, that of Lehesten in the Thuringian Forest may be mentioned.

In respect to mica slate and gneiss as building stones, gneiss, or highly gneisose varieties of mica slate, should be selected for situations exposed to much wet, as the finer grained, or more slaty varieties, more rapidly disintegrate; but where the building or any of its parts are likely to be exposed to much heat, as in the sides of chimneys and fireplaces, the true mica schist, or the fine-grained varieties, are preferable. The city of Freiberg is built of gneiss, and its streets paved with the same material.

Of the plutonic and volcanic rocks, the most important are, granite, syenite, porphyry, greenstone, basalt. Many varieties of granite are excellent building stones, and though expensive in working to definite forms, are most valuable. Some of the most important public works of England, France, and Russia (Petersburgh), are of this material. In selecting granite, those varieties in which the constituent minerals are very

small and the scales of mica superabundant should be avoided; and as a practical test it is wise to notice the country immediately around the quarry, as the sandy varieties rapidly disintegrate, and form accumulations of micaceous sand. The Hayter or Dartmoor granite, the Aberdeen granite, the Kingston (Dublin) granite, some beds of the Mourne or county of Down granite, and the Guernsey or Channel Island granite, are well known for their excellence. In some of the quarries the bedding of the granite is more defined than in others; and wherever this is the case, or where marked cleavages or joints prevail, the working is much facilitated. Many old Egyptian works and statues were formed of granite, and it is still used for colossal works, as it takes a fine polish: for example, the great fountain shell or vase before the Museum at Berlin, and the pedestal of the statue of Peter the Great at St. Petersburgh, are of Northern granite, being sculptured from erratic blocks. The splendid Scotch granite columns in the vestibule of the Fitzwilliam Museum at Cambridge are beautiful examples of a modern application of this rock to the arts. Millstones are occasionally manufactured of granite. As a road stone, those varieties which have at once a fine-grained and a close firm texture should be preferred, as the large crystals of coarser granite are liable to cleave into fragments. The specific gravity of this important stone varies from 2·5 to 2·6, which is very analogous to that of the metamorphic schists,—a circumstance which gives additional weight to Keilhau's opinion that it is in many cases a metamorphic and not an eruptive rock. Syenite is even a firmer stone than granite, and its specific gravity, which ranges from 2·5 so high as 3·0, approximates it to greenstone. Many beautiful varieties of this rock are found in Ireland. In Dresden, syenite is hewn into regular parallelopiped blocks for paving, a purpose for which its durability and firmness peculiarly fit it; and as a road stone generally it is excellent. Many ancient Eastern works were formed of it, and the Giant Pillar of Melibokus was fashioned out of one block.

Porphyry.—This term extends over a wide range of species, as it may be applied to any rock in which isolated crystals, usually of felspar, are imbedded in a distinct paste. As a building stone, all those varieties having a soft argillaceous paste must be rejected; but there are many which afford good rough building stones, and also good road stones, easily breaking into proper forms and sizes, binding well, keeping dry, and being tolerably free from dust,—a consideration too little attended to in the selection of road stones. From the beauty of its colours, some varieties of this rock have been largely used for columns, monuments, and vases. The red, brown, black, and green antique porphyries are well known to the student of ancient art. In modern times, the most remarkable porphyry works are at Elfdal, in Sweden, and Kolyvan, in Siberia. The Elfdal works have been established about sixty years; they are in the province of Dalarne, amidst wooded mountains, and in a wild country. The blocks are worked into form and polished by well-adjusted machinery; and most beautiful works of art as columns, vases, chimney ornaments, and tables, are produced, rivalling the rosso-antico, or ancient red porphyry. A magnificent vase of this porphyry, at the country palace of Johannsthal, is 10 feet high, and at its summit 16 feet in diameter: it rests on a base of granite. The principal dépôt of this manufacture is Stockholm. In the workshops of Kolyvan, in Siberia, equally beautiful specimens of art are manufactured, and forwarded in large quantities to Petersburgh. The blocks are sometimes of great size, 300 men being employed to draw a single block. Some of the porphyries of Hungary resemble the grey porphyry, the mordiglione of Roman artists. The specific gravity of porphyry varies from 2·4 to 2·6, and it may be observed that the beautiful polish it takes is a principal cause of its extreme durability; many works formed of it remaining uninjured for ages amongst the ruins surrounding them.

Greenstone.—The specific gravity of this rock ranges from 2·7 to 3·0, and though its extreme hardness, and the difficulty

of cleaving it without splinters, render it less fitted for regular buildings, it may be used with advantage as a rough building stone, and for a road stone is excellent. The porfido verde-antico, or green porphyry of the ancients, noticed under porphyry, is a greenstone porphyry, the base being greenstone, with white and green isolated crystals of felspar. The Corsican globe rock is a compact greenstone with globular concretions.

Basalt.—This rock, so remarkable for the columnar structure which is so beautifully exhibited by many of its beds, as at Staffa and the Giant's Causeway (see also fig. 17), has a high specific gravity, varying from 2·8 to 3·1. In the more dense varieties its very great hardness makes it difficult of use for squared work; but for rough building, and especially for sea walls exposed to much wear, it is excellent. For paving stones it would also be admirable, were it not that the surface becomes polished and slippery; but as a road stone it cannot be excelled, making at once a firm, durable, and dry road. Though not common, some of the sphynxes and lions of the Egyptians were formed of basalt.

Trachyte and the trachytic or felspathic lavas, and the various other products of ancient and modern volcanoes, naturally come into this section. In the county of Antrim largely, and in the county of Down in small quantity, trachytic porphyry has been found, assuming in Antrim a columnar structure. It appears also to be a product of the volcanic districts of New Zealand. It forms a handsome and durable building stone. Of other lava products, such as tufa, the Romans used them extensively, as is observed in the ruins of Pompeii: when porous, they are very light, and may therefore be often applied with advantage where that quality, combined with strength, is of importance: their absorbent quality renders walls lined with them very dry.

Ophiolite or *Serpentine.*—The mineral 'serpentine,' which name is extended to a massive and comparatively impure rock, is a bisilicate of magnesia, and has been well known from the earliest times. In all parts of the world, some of

its varieties have been used in the formation of images for idol worship, and in the manufacture of vases, columns, pipes, &c. The rich green and bronze tints of its finer varieties, and the high polish of which they are susceptible, render this stone highly ornamental and valuable, and in Saxony it is still extensively worked. When veining carbonate of lime, it becomes the ophicalce of Brongniart, of which the green marble of Galway is an example; when porphyritic, it is his ophite.

Limestone.—The mode of association of limestone with the metamorphic rocks is very interesting, and deserves especial attention. It is found interstratified with mica schist, in layers varying in thickness from mere film to several feet, and partaking of the metamorphic change, as shown by its highly crystalline structure. When the crystals are not too large, it becomes a granular marble, and when veined, as in the county of Galway, with green serpentine, forms a verde-antico. Such marbles as these, including the finest statuary marble, were formerly called primitive limestones; but it is now known that they are of various ages; the marble here noticed, and that of Donegal, belonging to metamorphic rocks of a remote epoch, whereas that of Carrara is comparatively recent. In metamorphic districts, such as the mica schist country of Derry, Donegal, Scotland, &c., this limestone becomes a resource for lime, but it is impossible to notice its mode of distribution and the narrow scale of its development, as compared with the mountain limestone of the carboniferous and the chalk of the cretaceous systems, without perceiving that the argillaceous or muddy strata predominated at the epoch of its deposition.

Metallic Deposits.—The plutonic and metamorphic rocks are the great dépôts of metallic ores in Europe; and though in South America the gneiss itself is less productive whilst the ores continue into the overlying strata, it is highly probable that the latter have not been free from the metamorphic influence, and that metallic veins have there, as in the crystalline schists, been connected with electric phenomena.

Iron.—The ore from which English iron is obtained is not connected with metamorphic strata, and will be noticed in its proper place. The celebrated Swedish iron is obtained from the magnetic iron ore connected with rocks of this class. In Taberg, in Smoland, this ore sometimes forms mountain masses. At Dannemora, and various other places in Sweden, Norway, Russia, &c., it occurs in beds, sometimes alternating with the metamorphic strata, and it has also been found associated with plutonic and volcanic rocks, as with basalt. The fer oligiste, specular or Elba iron ore, sometimes replaces mica in mica schist, and is associated with adularia at St. Gothard. The peroxide of iron forms veins and beds in this class of rocks, but is also, as well as the other ores of iron, found in other classes of deposits.

Manganese.—The peroxide has been found in this class of rocks, but in a practical sense it belongs to the sedimentary deposits.

Copper.—Copper pyrites, or bisulphuret of copper and iron, the most important of copper ores, occurs principally on the Continent in gneiss and mica schist; in Cornwall, and in the South of Ireland, in metamorphic schists, being varieties of clay slate; in the Hartz in similar strata (or the old grauwacke); and in Tuscany at the junction of serpentine trapp (gabbro) with the tertiary strata. This mineral occurs also in the zechstein, or magnesian limestone formation, in the bituminous or copper schist (kupferschiefer). In the Oural mountains, in Siberia, the double sulphuret of iron and copper is rare, but the simple sulphuret of copper replaces it, the strata being probably sedimentary: this ore occurs also in the porphyritic district of Tyrone. The other ores of copper do not here require a practical notice.

Lead.—Galena, or bisulphuret of lead, occurs in plutonic, metamorphic, and fossiliferous sedimentary deposits.

Silver.—Bisulphuret of silver, the most important of its ores, has been found in gneiss and mica schist and in their associated limestone, in greenstone slate, clay slate, syenite,

and porphyritic greenstone. It extends up to the zechstein; but it should be here observed, that in some of these cases, as in Mexico and Peru, the veins run from the metamorphic to the ordinary sedimentary deposits, and have therefore been manifestly connected with the cause of metamorphic action.

Tin.—Binoxide (deutoxide) is the most important ore. In Cornwall, the great source of British tin, and the most important one of the world, the ore occurs in granite, and also in killas, a partially metamorphic schist. In other parts of the world, it is either in granite, in metamorphic schists, or in porphyry, or porphyritic schists of the secondary class,—conforming thus to the general rule as to the influence of metamorphic action.

Mercury belongs especially to the primary and secondary fossiliferous classes, though found rarely in mica schist or the crystalline metamorphic rocks, and in Haute-Vienne dispersed in globules in granite. The rich ore of mercury, cinnabar, of Almaden in Spain, is in the grauwacke (primary) strata, and has been worked for ages.

Zinc.—Bisulphuret, usually associated with bisulphuret of lead. The carbonate belongs to various mineral deposits, extending even to the tertiary class.

Antimony.—Bisulphuret of antimony is rare, and found in veins traversing granite, gneiss, and mica schist.

Molybdena.—The bisulphuret is found generally, in small masses, in granite and mica schist, and occasionally associated, though sparingly, with ores of tin, as in Cornwall, &c., and still more rarely with copper pyrites, as in Norway.

Gold.—This precious metal has been found in Brazil disseminated in considerable quantity in quartzose and chloritic rocks, which must be classed in the metamorphic system; and it is most probably from the decomposition of these rocks that the auriferous sands, containing also platinum and diamonds, are derived. Gold has been found in other places in veins traversing metamorphic rocks; and it is without doubt from such rocks that the Wicklow gold sands have pro-

ceeded; and generally it may be stated that the far greater proportion of gold is obtained from such sands.

Platinum.—Found associated with gold in the auriferous sands of Brazil; in Russia, in the Oural mountains; and the discovery of it has been lately announced in France.

This general occurrence of metallic ores in rocks which have undergone a metamorphic change, though at very various epochs, their occurrence in veins, and the facts observed by Mr. Fox of the conduction of electricity by mineral veins, and the development of metals and minerals near the contact of highly metamorphic strata, stated by Keilhau, point strongly to an electric cause for their production, or rather their presence under such circumstances.

Veins.—As the term vein occurs frequently in this section, it is desirable to give a clear idea of its meaning. The word itself conveys an idea which at once distinguishes it from dykes, as it implies a waving rather than a rectilineal course; but in reality this distinction is not always preserved, as many veins, and particularly metallic lodes, are rectilinear. Veins may, however, be viewed in two lights; namely, those which are unconnected with any great extraneous mass of matter, as they originate in and are confined to the rock in which they occur, and those which seem to arise from and to be connected with some great extraneous mass. The first class may be found in all rocks, are often so fine as to be quite capillary, and frequently intersect each other, forming a complete net-work: they are considered veins of segregation, having been probably cracks into which the crystalline matter now filling them has been gradually removed from the surrounding mass. They are sometimes of quartz, and sometimes of carbonate of lime. The other class of veins is often connected with large masses of external rock, the matter of which is identical with that of the veins; and it has therefore been very generally assumed that such veins are veins of intrusion, although a different opinion has been promulgated by Keilhau, who considers them only as an advanced product of

metamorphic action. Where metallic veins pass through various strata, including the sedimentary, they have most probably originated in cracks consequent on the disturbing movements beyond their limits, and have been filled partly by segregation, modified as to its results by electric currents, and partly by sublimation. Some of these veins are of great magnitude, an example of which may be cited in the great ironstone vein of the red mountain near Schwarzenberg, which is between 40 and 50 feet thick, and as it stretches along the boundary between the granite and gneiss, and partly in the gneiss itself, has been followed for more than 20,000 feet.

Effects of igneous, and specially of eruptive rocks, on the earth's crust.—Several of these rocks have been important agents in the successive disturbances of the earth's surface.

The great extension of the granite group over the surface of the globe must be ascribed to very general, and not mere local forces; and in like manner the frequent co-existence of granite and metamorphic rocks indicates a connection in the causes which have produced them. In the Erzgebirge at Geier the granite has forced itself up, in three blunt hills, through the mica schist, which in its vicinity has been further changed into gneiss; and in the county of Cavan, in a similar manner, rounded hills of granite occur amidst an ancient metamorphic schist. In the former case the granite has evidently been protruded subsequent to the deposition, and even to the partial metamorphism of the schists, but the exact epoch of its protrusion is not determinable. In the granite of the valley of the Neckar, near Heidelberg, however, though its exact antiquity cannot be settled, there is a limitation as to its age upwards, as it has been laid bare by the denudation of the new red sandstone which had been deposited over and had once covered it; and such examples prove the repetition, at various epochs, of the action of elevating forces, by which the surface of the earth was disturbed and igneous rocks forced upwards. Confirmatory of these views, granite exhibits itself in two

forms, either constituting mountain masses, or appearing in veins. The veins are of various thicknesses, from a few inches to several feet, and it frequently happens that massive granite is penetrated by veins of granite of a different character: thus Leonhard has called the one, principally porphyritic from the presence of disseminated felspathic crystals, mountain granite; and the other, which is not porphyritic, vein granite. Granite, by acquiring hornblende, sometimes passes into syenite, and distinct veins of granite are frequently observed traversing syenite. In the Odenwalder the syenite is traversed by many granite veins, but a vein of the syenite in the granite has not as yet been observed, so that it has been assumed that the syenite is older than the granite. The passage of syenite into greenstone establishes a relation between the ancient and modern eruptive rocks. Another instance of such relations may be also cited in granulite or weisstein, where compact felspar becomes the principal constituent; for although this rock sometimes assumes an independent massive form, and in veins traverses granite, it has a close analogy to the trachytes or felspathic lavas. The veins of granite, granulite, and syenite, often contain large fragments of gneiss and other schistose rocks; and the strata adjacent to these masses are both much contorted and greatly metamorphosed. At Meissen and Hohnstein, in Saxony, the granite even overlies the quadersandstein, but it is supposed that this is owing to disturbance: at Christiania in Norway, and in the Hartz, it is found between the layers of primary schist and limestone, into which it has penetrated by veins, changing the schists into a species of hornstone; and such examples might be multiplied from many such districts. Greenstone, though closely approximated to the granite group by the intervention of syenite, approaches in like manner very near to the basaltic on the other hand, so that it affords a connecting link between them; but whilst granite and syenite exhibit only very obscure examples of intercalation or even superposition to stratified deposits, greenstone is often so closely connected with both the non-fossi-

liferous crystalline schists and the primary fossiliferous schists, not only occurring in intruded masses and penetrating veins but also in beds alternating with the regular strata, that Werner classed it with them. Where the schistose beds are penetrated by greenstone, the strata are often much contorted, and the consequent intricate structure affords another analogy with decided igneous rocks; and where the two classes of rocks are disposed in regular and parallel strata, distinct transition from one to the other can frequently be observed: but this is not always the case, as in some instances, especially where a thick bed of limestone occurs, the separation between the two is very distinctly marked. It is thus that, reviewing the various circumstances connected with this rock, the more decided metamorphic theorists consider it an ultimate result of metamorphism, whilst the eruptive theorists connect it with erupted rocks, and consider its alternating beds as the products of so many distinct eruptions. The more general aspect of this rock is characterized by knoll-like or conical masses, which are sometimes recognized at a distance as small lump-like excrescences projecting above the stratified deposit. The columnar structure is rare, but it is occasionally observed. The close resemblance between syenite and greenstone makes it desirable to have some rules for distinguishing them. Those of Cotta are as below.

Syenite.	*Diorite or Grünstein.*
The dark green hornblende, blended with the yellowish or red Labrador felspar and weathering nearly together, both form on the surface an iron-shot crust.	The mostly white albite weathers sooner than the dark green hornblende, so that the crystals of the latter project above the weathered surface.
Colour.—Reddish or whitish green.	Green, approaching to black.
Occasional Ingredients.—Almost constantly small brown crystals of titanit, and sometimes quartz and mica.	Iron pyrites and magnetic pyrites (simple sulphuret of iron).
Fissures, lined with epidote.	Also common.
Forms.—Massive and angular, and constitute mountain masses.	Conical: knolls, masses, small masses, layers, or veins.

Minerals and metals are sometimes extensively developed in this rock,—a remarkable example of which may be cited from the neighbourhood of Schwarzenberg, where it penetrates the

mica schist, by layers more or less parallel to the stratification; though such arrangement is sometimes so widely departed from, that, combining the divergence with the evidence of fragments of the adjacent rocks taken up by the greenstone, it has been suggested that the igneous matter has been forced into the fissures which have taken place in the natural lines of lamination of the strata. Some of these conformable dykes are more than 30 feet thick, and the ore is so abundant as even to conceal the original composition of the rock. The ores are especially magnetic pyrites, iron pyrites, arsenical pyrites, tin ore, black and brown blende, lead glance, and silver; and the minerals are garnets, vesuvian, chlorite, epidote, tourmaline, prase, mica, calcareous and brown spar, and many others. Granular limestone and dolomite occur in connection with this rock, as in other examples.

Serpentine is allied to greenstone, and exhibits similar physical features. Its veins penetrate the crystalline schists, as well as granitic rocks, and it appears to have been protruded amongst the beds of the Jura formation, being abundant in the Alps. The well-known mixture of serpentine veins in marble is a curious example of metamorphic action, as they indicate rather diffusion than penetration, and cannot be connected in many cases with any great mass. The fissures and cavities of serpentine are often covered with asbestus.

Porphyry Group, including felspar porphyry, pitchstone porphyry, and augite porphyry.—These rocks all affect a similar physical character, appearing in lump-like masses and projecting dykes into granite, crystalline schists, and various stratified deposits. They frequently appear as isolated hills amongst other rocks, and have been noticed in all parts of the earth. The felspar porphyry, including hornstone and claystone porphyry, forms extensive masses, and also dykes of great length, which frequently contain fragments of the rocks passed through, and are sometimes bounded by a breccia formed by their action upon them. The pervading form of this group of porphyries is rather angular than round, and tabular beds and columns are

common, so that there is a close analogy in structure to basalts. Metallic veins are rare in the porphyry itself, though more frequent at its contact with schists. A remarkable example of these rocks is seen in the Tharander Walde, where several powerful dykes proceed tangentially rather than radiating, from a round knoll more than a mile in diameter. The main mass lies between gneiss and clay slate, and dykes from it ramify through both. At the Zeisigsteines it becomes columnar, and at the Esberge still more so. The overlying rock is here the quadersandstein. Between Freiberg and Frauenstein, dykes many miles long cut through the gneiss, and are themselves penetrated by metallic veins. Pitchstone porphyry, including pitchstone and pearlstone, is comparatively rare, and is usually connected with other porphyries, which it either penetrates in mass or by dykes: it occurs in Saxony, in Hungary, and extensively in the island of Arran: it appears also in the felspar porphyry district of Antrim.

Melaphyr (*augite porphyry, augite rock, &c.*)—This rock is sometimes amygdaloidal, and generally appears either in small knoll-like masses or in irregular dykes, penetrating massive and schistose rocks, and effecting important changes in the fossiliferous deposits. The varieties of this rock are very numerous, as it becomes porphyritic from detached crystals of augite, of mica, or of felspar; but a negative character is obtained from the absence of quartz. Its bladder-like and amygdaloidal structure, and the occasional appearance of columns, approximate the rocks to the basalts. It has been rendered remarkable by the juxtaposition of magnesian limestone or dolomite in great masses, supposed by Von Buch to have been produced by a contemporaneous emanation of magnesian vapours from the interior of the earth acting on the pre-existing limestone.

Basalt Group, including clinkstone and trachyte.—This remarkable group brings up the working of ancient igneous forces to the very threshold of the existing epoch. In basaltic countries, isolated conical hills are common; such independent

knob-like masses of all sizes from 5 to 1000 feet in height, and from ten to many thousands in diameter, projecting above the surface of the country, and sometimes being connected together in one great mass. The basalt is sometimes like a stream of lava spread over other strata, and it is frequently found alternating with them: it has penetrated through all the ancient igneous rocks and through all the fossiliferous strata up to the post-tertiary, some of its varieties intersecting others. Where basaltic dykes have crossed other rocks, remarkable chemical and mechanical effects have been produced: granite gneiss and mica schist have been reddened, and (especially the mica), partially melted; clay slate, burnt and hardened; sandstone, reddened, glazed, and reduced to a columnar structure; stone and wood coal, charred; limestone, sometimes deprived of its carbonic acid, and frequently reduced from an earthy or compact to a crystalline state; shale, changed to jasper; fragments of underlying beds, raised to a higher level, and the regular strata disturbed and uplifted, though not to the same degree as by granite and porphyry, the chemical exceeding the mechanical effects in this class of rock.

Phonolith (clinkstone and clinkstone porphyry) and trachyte are not so widely spread as true basalts. Passages between clinkstone and trachyte may be traced, and, where they occur in masses, the larger generally possess more of the trachytic, and the smaller of the phonolitic character. Columnar and tabular forms of structure are observable as well as dome-shaped or conical hills. Trachytes, occasionally varying to phonolite, occur in the well-known Siebengebirge, in Hungary, in the South of France, and extensively as Andesite in the Andes.

Lava in its basaltic, greenstone-like, trachytic, porphyritic, leucitic, and slag-like varieties, exhibits a close analogy to the erupted rocks of all epochs. In order to comprehend the influence of the volcanoes which have produced them as a modifying geological force, it is necessary to bear in mind that earthquakes are a portion of their phenomena,—the earth-

quake often preceding the volcanic eruption, and both being the result of the movement of matter in the interior of the earth. It is thus that whilst the streams of lava which flow over the sides, and the dykes which penetrate the walls of the crater, illustrate the more ancient igneous products, the movement of the earth's crust, its upheaval or its depression, and the cracks which fissure it under the action of the earthquake, are equally illustrative of the mechanical effects of former forces of a similar nature.

In the great earthquake of Chili, 19th of November, 1822, the shock was felt along the coast for 240 miles, and by many natural appearances, such as the exposure of beds of shells at times of the tide when they were not before so exposed, it was ascertained that at Valparaiso the uplifting amounted to three, and at Quintero to four feet; and as the great chain or axis of disturbance along which the volcanoes are arranged is at a considerable distance, it is reasonable to suppose that all the intervening country had been similarly raised. There are traces of more ancient shocks by which the coast had altogether been raised about 50 feet. The rocks of the coast are granite and syenite, in which there are numerous parallel cracks which can be followed landward for 1½ mile. The effects of this earthquake could be traced over a space of 100,000 square miles.

An earthquake shook violently part of Wallachia on the 11th January, 1838; many parallel fissures were formed, and then filled by matter forced upwards.

The earthquake which destroyed Lisbon, 1st November, 1755, was felt in all Europe, so far as Norway, on the north coast of Africa, in several of the West India Islands, and by many ships at sea. At Lisbon, an adjacent hill was split in two, and the new quay sunk 600 feet below the water. The changes of level of the celebrated Temple of Puzzuoli, near Naples—the rising and sinking of the land in Scandinavia—the appearance of islands forced up—are all phenomena which exhibit the still continuing action of elevating forces. Jorullo,

in Mexico, affords an example of volcanic action combined with extensive elevation, and Skaptaar Jokul, in Iceland, one of a stream of lava which may vie with many of the ancient basaltic streams—being about 50 miles long, 12 miles wide, and on an average 100 feet thick. The contemplation of such wonderful effects of still acting causes prepares us to estimate forces which acted according to the same laws in former epochs. Whilst, therefore, water has worn down, transported, and re-deposited in nearly regular and horizontal order, or, in other words, restored the level of the earth's surface, the action of heat, in conjunction with electricity, &c., has tended to disturb that level, and to raise some portions of the surface above others. Such an elevation could not be effected without much disturbance and the formation of cracks, the general result being subject to much modification: where, for example, the elevating force acted on a point or small space, an isolated mass or mountain might be formed, and the cracks would radiate from a centre; or should the superficial pressure be diminished, the crust might be raised like a great bubble, and, finally separating at its apex, form the circular wall of what Von Buch calls a crater of elevation: if acting on the line of a crack, either one side might be uplifted, and thus form a steep precipice overhanging a plain,—an appearance not unusual in nature,—or both sides, so as to form two precipices, with a valley of elevation between them; and again, if some cracks are formed transverse to others, and upheaving takes place, there will be various modifications of the primary ridges. These forces, continuing to act at intervals for ages, have produced the great and the cross chains of mountains. Von Buch, pursuing these inquiries, observed that in certain districts the mountain chains, the strike of the strata with some modifications, and even the great valleys, had certain predominant directions; and Elie de Beaumont, extending Von Buch's researches, founded upon them, in 1830, his Theory of Elevation, according to which *all mountain chains of the same age have the same general direction.* He assumed that

the earth's crust has been elevated into mountains at various periods by forces acting at all places in parallel directions; and to determine the relative ages of such upheavals, refers to the fact, that uplifted and highly inclined strata must have been in existence prior to the upheaval which disturbed them, and horizontally deposited strata overlying the inclined must have been formed subsequently to such upheaval; and thus the epoch of elevation must have exercised much influence on the direction and grouping of sedimentary deposits. M. Elie de Beaumont has in this manner distinguished about fifteen systems of elevation, according to their age and direction, of which the most remarkable are the twelve following.

1. *System of Westmoreland and Hundsrück.*—Direction of elevation, N. E. $\frac{1}{4}$ E. and S. W. $\frac{1}{4}$ W. No newer strata than the Silurian, and probably a part of Devonian, uplifted. This includes the Eifel, the Taunus, the Isle of Man, and South Shetland. 2. *System of part of the Vosges.*—Direction, E. 15° S., W. 15° N. Mountain limestone, but not the coal-bearing strata, uplifted. To this belong the hills of Bocage, in Calvados. 3. *System of the North of England.*—Direction, S.—N. The coal-bearing strata are the most recent affected in this elevation. 4. *System of the Netherlands and of South Wales.*—Direction, N. E.—S. W. The whole of the coal formation affected. 5. *System of the Rhine.*—Direction, S.—N. or S. S. W.—N. N. E. Strata to the zechstein (magnesian limestone) uplifted. The Vosges, Schwarswald. 6. *System of Bohemian and Thuringian Forests.*—Direction, S. E.—N. W. The keuper is the newest formation disturbed. La Vendée, Bretagne. 7. *System of the Erzgebirges.*—Direction, S. W.—N. E. The oolite or Jura, but not the quader-sandstein, affected. Cote d'Or, Mount Pilas and the Jura in part. 8. *System of Monte Viso.*—Direction, N. N. W.—S. S. E. The older but not the newer chalk affected. 9. *System of the Pyrenees and Apennines.*—Direction, N. W.—S. E. The younger or upper chalk, but not the tertiary strata, affected. This system being parallel to No. 6, it is often difficult

to separate one from the other. Hartz, Teutoburger Forest, &c. 10. *System of Corsica and Sardinia.*—Direction, S.—N. The lower tertiaries, but not the upper, affected. The basalt of Hesse. 11. *System of the Western Alps.*—Direction, N. 26° E.—S. 26° W. The new tertiaries affected. 12. *System of the main chain of the Alps, from Wales to Austria.*—Direction, W.—E. or E. N. E.—W. S. W. A portion of the post-tertiaries affected. Monte Ventoux, Leberon.

Such is the theory originally propounded by De Beaumont, bringing down the evidence of successive elevations almost to the existing epoch, but its application requires caution. Many mountains have evidently not been raised by one impulse, but by several acting at different times, though in the same direction; and igneous rocks of different ages may be traced along a line common to several successive elevations; nor can the assumption that the elevations of any one epoch have every where been effected in parallel and straight lines be admitted: it would indeed be difficult to follow out such lines of elevation over the earth's surface, more especially as the more frequently elevations are repeated in nearly the same direction, the more difficult it becomes to distinguish one from another,—a difficulty perceptible even in the twelve great systems enumerated; but though the generalization was too enlarged, it must be acknowledged that the groundwork of the theory is correct, and that its promulgation has had a most powerful effect on the progress of geological science.

The fact has thus been established, that at successive epochs the earth's crust has been broken up and elevated, whilst various igneous rocks, the most superficial of which was probably granite, were lifted up and forced into the cracks of the disturbed crust; but the mode in which the great elevating force has been developed has yet to be investigated, and here indeed is a difficulty, as direct observation can only extend to a mere film of that earth the surface of which it has affected in so striking a manner. The facts, however, of disturbance are palpable, and the nature even of the forces

producing them can be inferred by reasoning, though not demonstrated by observation. Electricity may be fairly classed with these forces, though probably only as a secondary cause; and it may be affirmed on sufficient reasons that heat was a primary one. This subject was learnedly discussed in 1837 by Gustav Bischoff, who, assuming a fluid condition of the central portions of the earth from heat, demonstrates from physical considerations, that hot springs, the production of massive rocks from the cooling of the fluid mineral matter, volcanic eruptions and earthquakes from the expansive force of steam produced by contact of water with the still heated and fluid internal mass, are all natural consequences of such a condition.

Sir H. Davy proposed a chemical theory of earthquakes, founded on the properties of the newly discovered bases of the alkalis and earths. These bodies, when brought in contact with air and water, are oxydated with great rapidity, producing an intense ignition: he therefore considered it probable that potassium, sodium, calcium, &c., exist in great quantity in the interior of the earth, and coming into contact with water which had penetrated by cracks or filtration, is suddenly ignited and oxydated, giving rise to volcanic fires and to the formation of various stony compounds, which, as lavas, are then erupted. Independently, however, of other objections which have been urged against this beautiful and apparently simple theory, it may be stated that the low specific gravity of the alkaline and earthy bases is opposed to their existence in large quantity in the interior of the earth.

The theory of Cordier, which is purely thermometrical, and is that one most generally adopted by Geologists, may be expressed under the following heads:

1. The earth has an internal temperature, which is independent of the solar heat, and increases rapidly with the depth.

2. The rate of augmentation is different at different places; in one country it may be double that of another, and the

difference is *not* in a constant ratio with either latitude or longitude.

3. As the total mass of the earth is about 10,000 times greater than that of the waters connected with it, it is more probable that the original fluidity of the earth was due to heat than to aqueous solution. The heat was very great, as the present temperature at the centre of the earth, supposing a regular progression in the increase downwards, exceeds 3500 of Wedgewood's pyrometer = 450,000° Fahrenheit.

4. A temperature of upwards of 12,000° Fahrenheit, which is sufficient to melt most of the known rocks, would exist at depths below the surface varying from 80 to 160 miles, supposing the increase to be regularly progressive; but it is highly probable that the dense fluid portions of the earth are much better conductors of heat than the crust, and therefore that this high melting temperature is acquired, and that the actual fluid portion commences, at a still less depth.

5. As the crust of the earth, leaving out of consideration sedimentary deposits, has been consolidated by cooling, its formation must have taken place from without inwards, so that the more superficial crystalline rocks are the most ancient; and this accords well with the small density of granite which appears to have been uplifted under so small a comparative pressure as not to have been actually erupted. The thickness of the crust will continue to increase until the cooling has attained its final limits.

6. There is no reason for believing that the solid crust can be more than from 60 to 100 miles thick, and it may be very much less: it is probably very unequal, as shown by the variation of internal temperature, which cannot be explained by different conductibility alone. It possesses some degree of flexibility, and the phenomena of earthquakes are due to the expansive force exercised by the fluid nucleus within it, under the influence of the internal heat and of the pressure it exercises upon it.

7. The solid crust continues to contract as its temperature

diminishes in a greater ratio than the central mass; and as the velocity of rotation must increase as the diameter of the planet diminishes, there will be a tendency to diverge further from the spherical form, and hence the fluid matter within will press against the contracting crust, and produce volcanic eruptions. M. Cordier has calculated that a contraction of $\frac{1}{12350}$ of an inch in the mean radius of the earth would be sufficient to force out the matter of a volcanic eruption. In this hypothesis, the zones of least thickness of the earth must be the sites of volcanoes. Professor Rogers, of Philadelphia, has traced the progress of three great earthquakes in the United States, the synchronous lines of which, or lines along which the shock was felt at the same moment, extended 300 miles in a direction from N. E. to S. W., the progressive motion being to the eastward, at the rate of 30 miles a minute.

It is highly probable that electric forces called into action by change of temperature share in the production of these effects, and that partial differences in the conductibility of different strata increase or diminish the intensity of the shock, and by producing local cracks are especially the cause of the various subterranean noises which accompany these great and fearful phenomena. It may be added that the beautiful discussion by M. Rozet of a series of pendulum experiments, compared at once with the geodetic measurements in France and with barometric observations, has proved that lofty mountain chains are not the only evidences of the disturbance of the crust, but on the contrary, that the apparently level surface of the earth exhibits many undulations which, by their effects on the pendulum, have evidently been produced by the swelling up of denser matter within them. M. Rozet has further established as a fact that the ocean, considered by so many English Geologists as possessing an invariable level, must participate in these movements, and conform itself to the varying level of the solid crust. "We find," he says, "that the true level of the ocean is below the mean elliptic level in the Polar Sea, on the coasts of Spitzbergen and Greenland, as also

on the coasts of Great Britain, at the Equator, and in the Southern Ocean, and that it is above that level on the coasts of Norway and at the Cape of Good Hope." This inequality of absolute level in the ocean, consequent on the protuberances and hollows of the crust of the earth, must have varied with, and been in proportion to, every great disturbance, or to the amount of matter protruded above the mean elliptical level of the liquid nucleus. By the calculations of M. Rozet, the mass of the Alps, if entirely composed of basalt, should deflect the plumb-line only $13''\cdot5$, whereas on the eastern flank of these mountains the deflection amounts to $28''$, and on Mount Cenis itself to $8''\cdot5$; whence it is concluded that this great deflection was due not merely to the mountain itself, but to the dense matter of the interior of the earth forced into the protuberance, from the summit of which the mountain chain had been elevated. It is not therefore the sedimentary deposits alone which have acquired an irregularity of surface; the general form of the earth has been altered from its original condition, not by one but by many commotions, increasing in intensity on approaching the existing epochs, and as the thickness of the solidified crust has continued to increase, the most recent chains of mountains are necessarily the most elevated. These inquiries, combined with those of Mr. Hopkins, of Cambridge, will, it is hoped, ere long reduce the disturbances of the earth, and the elevations and depressions consequent thereon, to the laws of exact science.

CHAPTER V.

Petrifactions—Petrifying Substances, and Modes of Petrifaction—Conditions of Petrified Bodies—Distribution of Fossils.

THE relics of ancient worlds discovered in the mineral strata of the earth may, from their forms, be classed either in the vegetable or animal kingdoms. The first observers of these remarkable bodies did not overlook their resemblance to still existing organisms; but, unable to account for their composition and situation, either considered them lusus naturæ, or, admitting them to be the relics of organized bodies, did not perceive the specific distinction between them and still living creatures, and ascribed their position in the earth to one great phenomenon—the Deluge. The labours of modern Philosophers have fashioned Geology into a new science, by discovering in these bodies proofs of many successive phenomena, such as the appearance and disappearance of organic bodies, under new forms and combinations suited to the varying conditions of the earth's surface. Of the number of plants which have thus lived at ancient epochs and passed away, some idea may be formed from the rich collection of Goëppert, author of 'Les Genres des Plantes Fossiles,' &c., which contains 3254 specimens of vegetable petrifactions; namely, 236 from transition strata (Cambrian and Silurian), 1548 from the carboniferous, 34 from the 'grès bigarré' and 'calcaire conchylien,' and 61 from the 'keuper,' (or 34+61=95 from the trias or new red sandstone), 61 from the lias and oolite, 242 from the green-sand, chalk, and gypsum, 742 from lignites, 259 of unknown localities, and 50 of recent forms. These bodies occur in three conditions.

1. Stems, leaves, flowers, fruits, interposed between layers of stony or earthy matter, and either slightly browned, or in various states (up to the most perfect) of carbonization.

2. Impressions of the bark of plants, the interior of which is either empty or filled with stony matter.

3. More complete petrifactions, in which the whole of the interior mass, as the several organs, cells, and vessels of the plant, are *filled* with stony matter, not *changed* into stone, as is commonly said.

The first of these conditions M. Goëppert illustrates by two experimental imitations of the distribution of fossil plants in the shales and grits of various geological epochs. First, by the dry method: living plants, particularly ferns, were placed between layers of soft clay, which were then dried in the shade, and afterwards subjected to heat varying in intensity up to a red heat. According to the degree of heat, the plants were found either slightly browned or perfectly carbonized; and when either powdered coal or asphalte had been mixed with the clay, they exhibited a shining black tint, and adhered to the layer of clay. When the heat had been pushed to redness, and the plants were entirely consumed, impressions of both faces were found, just as in the grits of Silesia. Second, by the moist method: the plants placed between layers of clay were plunged 6 feet deep in a ditch, and left there for a whole year, when they were found more or less browned, as is the case also with plants naturally immersed in the mire at the bottom of ponds, and so strongly resembled the impressions of fossil plants that they might have been mistaken for them.

The second condition has as yet not been fully illustrated by experiment, as it requires a combination of circumstances not easily imitated on the small scale. In this state the bark of the plants sometimes remains resembling coal, and all its external peculiarities are impressed on the surrounding matrix, whilst the markings of the internal surface are exhibited on the stony cast formed within it. In cases like this, the cast and the mould have been taken for different bodies. Sometimes the bark is reduced to a film of coaly powder between the impression of the mould and the cast; and as the de-

composition of the thin bark of such plants preceded the formation of the cast, the impression of the mould represents the original external surface of the plant, not that of the interior, as in the preceding case. When the process of decomposition has taken place under pressure, the stems are more or less flattened, according as the pressure has succeeded or preceded the petrifaction; and in some calamites the opposite surfaces have been pressed close together, the whole internal substance having been removed before the consolidation of the surrounding mass had secured it from the effect of pressure.

In the third condition of vegetable petrifactions, the petrifying matter has infiltrated into and been solidified in the interstices of the cells and vessels, the walls of which have been more or less preserved; the mineral petrifying substances soluble in water being either silica (the most general mineralizer), carbonate or sulphate of lime (not so common), peroxide of iron, smooth clay, or a mixture of several of these ingredients. This process is still going forward, as the following examples cited by M. Goëppert prove. Specimens of oak received from M. Cotta and from M. Laspe were taken from a brook near Gera, having, in an unknown space of time, been fossilized by carbonate of lime, the presence of which was detected by an attempt to saw them: they are so hard as to take a fine polish, their vessels and cells being entirely filled with carbonate of lime, excepting some of the medullary rays. In a specimen of beech, from a Roman aqueduct in the principality of Buckebourg, the petrifaction is confined to cylindrical spaces which traverse the ligneous structure longitudinally, and were probably vacant spaces occasioned by decomposition, and filled up by the stony matter. The wood surrounding the petrified portions is perfectly sound; and under the microscope the exact identity of the structure of the woody and stony portions can be clearly traced. On applying an acid, the earthy matter was removed, and the ligneous texture in the oak was still found to contain tannin, so that perfect decom-

position had not preceded petrifaction. Peroxide of iron, which is constantly forming, is well suited to the petrifying process. The stave of a cask which had probably been immersed in the well of the castle of Gotha for one hundred and fifty years, is in part, especially at the junction of the hoops, petrified by this substance, and so hard as to take a polish by friction. The iron having been removed by muriatic acid, the wood continued in a solid and coherent state. Examining in a similar manner calcified specimens of the fossil woods of the ancient world, from various localities and of different ages, including that from Craigleith, in Scotland, the same results were observable, the woody fibre being still exposed by the action of very dilute hydro-chloric acid. In some specimens, a bituminous oil, emitting a mixed odour of creosote and petroleum, was obtained,—an additional proof of the formation of bitumen under aqueous pressure. M. Goëppert was unable to discover any recent petrifaction by silica, although such had been said to exist.

Wood fossilized by gypsum is very rare: a specimen from Katscha, in Silesia, weighing 4 quintals, is in the museum of the University of Breslau. The ligneous fibre is only in part fossilized, being otherwise flexible and browned. In silicious vegetable fossils, M. Goëppert removed the silica by hydrofluoric acid, and found the woody fibre so well preserved in many of them, that it might be used in determining the genus of the plant. When in woods treated with hydro-fluoric acid there is no trace of organic matter, it has been doubtless removed after fossilization, either by long aqueous action or by heat. This was verified by submitting slices of the petrified coniferæ of Silesia, which still retain a portion of ligneous fibre, to the action of a furnace, when the fibre was destroyed, and the specimens, before variously coloured, became uniformly white and opaque, and the characteristic structure of the coniferæ very distinct. It is, however, remarkable that the ligneous fibre has been preserved in some fossil woods found in igneous rocks, as porphyry, basaltic tufa, and even basalt,

and which must have been subjected to heat; and it therefore appears certain that water must have been a principal agent in the removal of organic matter. M. Goëppert examined many specimens of the fossil wood of Buchau, in the county of Glatz, which had been rolled about in a brook running from the mountain, and he ascertained that the more they were rounded and had been subjected to the action of the air and water, the less organic matter they contained, the diminution taking place from the centre outwards. In this instance the disorganization was effected in a very short time: is it not then surprising that any traces of organic matter should be found in specimens which have been exposed to the air for more than 1000 years? Two specimens of fossil wood from the Desert of Egypt, which, from their appearance, had evidently at some remote epoch been rolled by water, still preserve a large quantity of organic matter. The agatized woods of Hungary occur in the horizontal beds of a conglomerate of pumice which forms the basis of the trachytic group; they are externally beautifully transparent from the absence of organic matter, (which, however, exists in the narrow cells of the annular rings,) and from the water which is contained in the outer portion: exposed to the flame of the blow-pipe, they lose their transparency, become white and opaque, and, from the dilatation of the water, split along the direction of the ligneous fibre, so that it is possible to separate the ligneous cells from each other. In the Tokay fossil wood, the colour, as well as the organic matter, is still preserved. In the Antigua agatized palms, the delicate spiral vessels can still be recognized. In general, the more organic matter left, the more coloured the specimen; but at times it takes its tint from the mineral matter itself. If the organic fibre of fossil plants exposed by the removal of the stony matter by an acid be subjected to great heat, it is burnt away, and leaves, as in recent plants, a silicious skeleton,—another curious analogy between the animal and vegetable kingdoms: and when we reflect on all these curious facts, can we refrain

from a sensation of admiration at the thought that not merely the forms of bodies, but actually the organic matter of ancient creations, has been preserved for our contemplation and study?

Reviewing also the various circumstances and conditions of fossil vegetables, extending from the most remote up to the existing period, M. Goëppert concludes that the forces which are now in action were sufficient in the past epochs for producing the effects observed, and that the water of the ancient world *did not* possess a higher solvent power than that of the present. Water will dissolve about $\frac{1}{1000}$th part of silica, and although a recent silicious fossil has not been found, the concretions on the bamboo, called tabasheer, and the large quantity of silica deposited in some other living vegetables, are sufficient proofs of the ease with which it enters, as a fossilizing body, into the vegetable structure.

The connection of this inquiry with the formation of coal and lignite is evident. M. Wiegmann made experiments on the formation both of turf and of lignite in the moist way, and many examples might be cited of corresponding changes within comparatively small intervals of time. In the mines of Charlottenbrunn, fragments of ancient carpentry had been changed into lignite. Specimens of wood-work were sent to M. Goëppert by M. Schroëtter, from the iron mines of Zurrach in Stiria, where, in the space of less than sixty years, they had been changed into resinous lignite; and others by Le Chevalier Kalina, from the sepulchres of the aborigines of Bohemia. And as a proof that even piciform coal has been formed by immersion in water under pressure, M. Goëppert cites the fact that beds of such coal actually alternate with still flexible lignite in the lignite mines of Zittau, in Upper Lusatia. M. Liebig states that in disintegration the hydrogen alone escapes; but that in putrefaction, oxygen also is disengaged. If, then, this latter change takes place under a high pressure, and at an elevated temperature, considerable quantities of carbonic acid will be disengaged, and much carbon be deposited in combination with a part of the hydrogen of the organic substance,

and coal and some lignites have probably been the result of such a metamorphosis. M. Link has also endeavoured to shew, by comparative microscopic observations, that turf and coal are analogous in structure, and have proceeded one from the other; and the occurrence of stems of trees in coal is not opposed to this view, as they are also frequently found in successive layers in the deep turf of Ireland. The formation of coal by immersion in water, under pressure, was, however, suggested long since by Dr. McCulloch. A similar inquiry has been instituted by Messrs. Mareel de Serres and L. Figuier, into the general principles of petrifaction, and as an illustration of them they refer to the petrifaction of shells in the Mediterranean. These authors suppose that the waters of the ancient ocean did possess a higher solvent power than they do at present; but in reality this is an apparent rather than a real difference, as the presence of the alkaline matter deposited at various epochs, in combination with silicic and other acids, must have enabled the water to act more powerfully as a solvent than it now does. In the action of this, as of every other force, the tendency is to a resulting equilibrium. *If* it has *now been attained*, the same processes will continue, but without producing any difference in the great whole of the animal, vegetable, and mineral kingdoms: if it has not been attained, such a difference, however gradually, must be produced. The long continuance of the present assemblage of created beings, without any apparent variation in the effective condition of the atmosphere, is a strong reason for believing that an equilibrium had been attained; and it may be assumed, that until such had been the case, the variations must have been sufficiently rapid to induce a much more frequent change in the aggregate of organic existences than can now take place in a world which has only lost, during 6000 years, about twelve vertebrate animals, and that principally from the action of man, although the distribution of such animals has been materially modified by the local extinction of some, and the lateral extension of other species.

Messrs. Serres and Figuier remark, that in order to induce the petrifaction of organic bodies, in which process the animal matter is replaced by mineral matter which preserves their most delicate forms and markings, they must be plunged in a considerable body of water, containing in solution a sufficient quantity of silicious and calcareous salts. The first part of this condition was specially fulfilled in the ancient world, when the waters occupied a much larger space than they now do, as shown by the general nature of geological deposits; and as regards the second, there can be no doubt that the dissolved salts were in sufficient abundance. In palæozoic petrifaction, carbonate of lime was the principal agent, and the fossilization was complete in proportion to the abundance of that salt present. In gypseous, argillaceous, and even sandy deposits, the petrifaction is imperfect and the shells of mollusca are only in part preserved, whereas in calcareous deposits it is complete. In respect to the power of water to dissolve this salt, it is only necessary to observe, that though carbonate of lime is insoluble in perfectly pure water, it is soluble when an excess of carbonic acid is present, as is always the case in nature; and that in consequence *bicarbonate* of lime exists in sea water, in an appreciable quantity, affording one of the many examples which occur in nature, of a balance between the formative and destroying causes constantly in action. Innumerable springs charged with carbonic acid dissolve the carbonate of lime of ancient formations, and carry it to the ocean, whilst the mollusca, &c., again withdraw it, and liberate the carbonic acid to return to the atmosphere. The shells of the mollusca again pass into new mineral deposits, either whole or triturated into powder; and the same may be said of the corals and other zoophytes.

Silica is the next most important petrifying substance, and even exceeds carbonate of lime in the extreme delicacy and fidelity of the restoration it produces. Those portions of the organic body which were capable of preserving their form for a sufficiently long time, are almost always petrified by car-

bonate of lime, but those of less consistency are in a silicious state. This is specially the case in the more purely animal portion of the organic structure; the ligaments of gryphites being often silicified, whilst the shells are calcareous; the shells of ananchites and other echinida of the green-sand calcareous, whilst their interior is either partially or wholly filled with a silicious cast; the alcyonia and sponges being usually silicified, and often in that state (as in the chalk) disseminated in the midst of calcareous rocks. These and other observations have established a strong ground for assuming, if they have not positively demonstrated, that there exists an elective affinity between silica and animal matter; and it is highly necessary, in the examination, to keep this fact before the mind, as different parts of the animal structure will be preserved in the two states of calcareous and silicious fossilization.

In regard to the solution of silica, it has already been stated that the water of almost all mineral and thermal springs contains a portion of silica, that it occurs in most rivers or streams, that it abounds in the stems and membranes of many vegetables, that heat and pressure combined favour its solution, —as is shown by the great quantity deposited at the foot of the boiling Geysers of Iceland,—that its solution is greatly favoured by the presence of an alkali which is usually afforded by the decomposition of rocks; and further, that in the gelatinous or nascent state, in which it always occurs on the decomposition of a mineral, it is readily soluble. Silica, therefore, must have been in solution prior to the formation of rock crystal, and, probably, in a gelatinous state when forming chalcedony, opals, and some of the flints and cherts of various geological formations. Oxide of iron, anhydrous or hydrated, and bisulphuret of iron, have also entered into the formation of fossils: in respect to the latter, the change, as in silica, is principally produced on the animal substance; for example, the ammonites in shale exhibit a mere film of shining iron pyrites, which has replaced the animal membrane.

The second section of Messrs. Serres and Figuier's re-

searches relates to the highly interesting question of the existence of *recent* petrifactions in our present seas, analogous to those of ancient geological times. In the Mediterranean, shells are immersed in a sufficiently considerable mass of water which contains in solution a notable quantity of carbonate of lime: the conditions are therefore present, and the question is, does the analogous result follow?

The officers of the French Engineers submitted to Messrs. Serres and Figuier specimens from the neighbourhood of Algiers, of masses of shells transformed into a crystalline white limestone of a peculiar lustre, like that of alabaster. In these shelly masses, small rolled pebbles are observed encrusted by a stalagmitic glaze, which appears to be similar to the cementing substance which binds the pebbles together. The shells are all of recent species of the genera pectunculus and cardium, with a few univalves, and the rock itself is considered by the officers of Engineers to be decidedly of recent origin. As bearing upon this interesting fact, may be cited the very remarkable recent conglomerate formed on the shore of Santa Maura, and at other localities, and which in its cohesion is fully equal to many ancient rocks of the same description; and as an example of the continued tendency to such aggregations, even from other than calcareous agencies, may be cited an interesting specimen, also from Santa Maura, presented to the author of this volume by Mr. Cottam, in which several pebbles have been agglutinated firmly together by the decomposition of a nail, to which they still strongly adhere. A similar instance has occurred at one of the batteries of Portsmouth, where a conglomerate has been formed round the iron shoes of the piles.

Messrs. Serres and Figuier state also, on the authority of others, not having examined specimens, that the cardium edule, in a petrified state, forms considerable beds at the mouth of the Somme, and that at Caneale the shells of oysters have been petrified in the same manner as in the Mediterranean.

That shells should now be petrified, it is necessary that they should remain a long time immersed in water or in the sea. Abandoned on the shore, they exfoliate and disintegrate, are gradually broken up, but are not petrified; but the phenomena are very different when they are plunged in the water. When shells are abandoned by the animals, the first change they experience is a loss of colour, as is also observed in the solid tubes of annelides (dentalium), and in the stony polypifers: the substance is then altered, and as many of the tubercles, ribs, &c., disappear, the structure of the internal laminæ becomes displayed, and as the change proceeds, the interior of the shell is sometimes filled up by agglutinated and hardened sand, and the whole structure has at length undergone a change so perfect, that had not the crystalline carbonate preserved the form of the shell, it would be impossible to determine its origin. Some striking examples of this change are adduced; and in reply to the objection sometimes urged, that such fossils may have been washed out of tertiary beds, Messrs. Serres and Figuier observe,—1stly, that shells are found in the Mediterranean in all stages of the petrifying process, from simple discoloration to the complete transformation into crystalline carbonate of lime; 2ndly, that the molecular structure of recently petrified shells is very often different from that of ancient fossil shells, the first being usually crystalline, the others usually compact. But it is here right to remark on this statement, that in many ancient fossil shells the crystalline structure of the shells is very perceptible, distinguishing them at a glance from the surrounding compact limestone; and this resemblance between the old and new is therefore another confirmatory argument in favour of the identity of the process at all ages of the world.

By a comparative analysis of the substance of living, of recently petrified, and of fossil shells, genera common to the three epochs of comparison being selected, the effects of petrifaction were tested; and it was ascertained that a portion of animal matter was still existing in shells of the pliocene form-

ation, that is, of an epoch antecedent to the present condition of the earth; and the resemblance, as to composition, of the recent shells petrified in the bosom of the Mediterranean to those which had undergone that change in the beds of the tertiary epoch was fully established.

Next to the mineral condition of the fossil, is the petrographic constitution of the bed in which it occurs. Organic beings are not only restrained as to the medium in which they live, but are also limited in regard to the peculiar collocation of circumstances suited to their individual existence: thus, a fish may be marine or fresh-water, and may be framed to live in open and deep seas, or to frequent rocky coasts and clear water, or to delight in the muddy shallows of estuaries; and in a similar manner the mollusca are regulated in their habitats by the necessary requirements of their organization;—a limpit being attached to a rock, and able to sustain the beating action of the wave,—the cockle inhabiting the gently-sloping sandy shore in shallow bays,—the myacea burying themselves in similar strands,—the pinnæ frequenting the muddy bottoms of deeper waters,—whilst many genera with strong shells can bear the force of currents, and rest uninjured on shingle banks or rocky bottoms. As the Naturalist, therefore, does not look for the animal suited to a muddy bottom on a shingle bank, or for the thin-shelled spatangus at the bottom of a rocky cliff exposed to the violent action of the tidal current, so the Geologist must exercise a like caution in his research, and remember that—

1st, A peculiar petrographic constitution in a stratum will be accompanied by a peculiar palæontological assemblage of fossils.

2ndly, That such a palæontological assemblage does not naturally include genera and species suited to strata of a different petrographic constitution.

When, therefore, genera or species peculiar to one form of mineral stratum be found in another, they are rare, much less developed, and less distinctly characterized than in the stratum to which they properly belong.

Combining the actual mineral structure of the stratum, which is a result of certain necessary conditions, with the modifying circumstances of position, deposits may be considered as shore or littoral deposits, shallow-sea deposits, deep-sea deposits, coral-bank deposits, &c.

An adaptation to the circumstances of the deposit influences the occurrence of all bodies, and it may be assumed, as a very important and almost universal character, that in all organisms of the coralline type the shell or crust is massive, and marked by ribs, striæ, spines, knobs, and other peculiarities, which, whilst they doubtless added to their fitness for opposing the contingencies of their peculiar location, now afford so many valuable characters for studying them as inhabitants of an ocean long since passed away. Deposits which may be called shingle, being the result of the more active wear of the waves, are often intimately connected with coral banks, but also accompany and link together all the petrographic forms of deposit. They possess few zoological peculiarities, borrowing, as it were, the characters of the several deposits with which they are connected, by receiving from them the fragments of their various organisms, which are gradually, as they are carried along, worn down, passing through an oolitic state into an impalpable paste. Muddy deposits, such as marls, compact and sub-compact limestones, together with sands and sandstones, constitute another important class, and exhibit a totally different zoological assemblage: the corals are of spongy and encrusting genera, and generally without apparent base; crinoids are rare, scattered about, and generally of unattached genera; the echinida are less rare, particularly the true echini and their congeners. The spatangi abound in muddy and sub-sandy deposits. Of the asterida, the genera asterias and ophiocoma are characteristic of muddy deposits, and of fine sands and gravel. Of the acephalous mollusca, the genera which abound are, solen, pholadomya, myopsis, pinna, tellina, mytilus, modiolus, corbula, isocardium, cucullea, and amongst the ostracea, especially gryphæa and exogyra. In

the gasteropoda may be noted, rostellaria, pterocera, natica, turritella, fasciolaria; and amongst the cephalopoda, the genera nautilus, ammonites, belemnites, being either rare or abundant, according to the variations in the form of the deposit. Fish with pavement-like teeth are very characteristic of these mud deposits; and reptiles are especially abundant in the Jurasic beds, though they are locally rather than generally distributed, occurring in what may be deemed muddy shore deposits. A general and constant character of all zoological assemblages in muddy deposits, is that the prevailing genera and species are provided with shells or coverings not fitted to withstand the wear of transport, being smooth and thin; and in those genera which possess a thick shell, the tissue is nearly non-elastic and easily disintegrates. It may be also stated, as distinctive of muddy bottoms, that the genera are more frequently free than attached, even the stems of pentacrini not exhibiting strong roots, having been probably fixed by fibrillæ or simply immersed at their base in the mud.

The sub-pelagic and pelagic forms of muddy deposits, though corresponding to the littoral form in their petrographic conditions, are distinguished from it by zoological peculiarities.

The deep-sea or pelagic deposits are very uniformly constituted, homogeneous, regularly stratified in continuous and often massive beds, except where modified or disturbed by the action either of currents or of elevating forces. In these deposits, large spaces are often deficient in organic bodies, or contain only their débris, together with those spongy and fibrous corals which are supposed to inhabit the waters of great depths; and where cephalopoda abound, the species differ from those which inhabit muddy shore deposits. M. Gressly arrives at these important deductions:

1. Each class or form of deposit presents characters, petrographic, geognostic, and zoological, peculiar to itself, and distinct from those of any other class or form of deposit, although of the same geological epoch.

2. That the same class or form of deposit, as regards its

petrographic and geognostic condition, exhibits very analogous zoological characters in each successive geological formation in which it occurs.

These laws are of great interest, and highly important in the application of zoological characters to the determining of geological formations; but in applying them it is necessary to take into account every disturbing or modifying influence, in order to separate, in any stratum, those organisms which are peculiar to and must have found a fitting habitus in it, from those which have only been brought into it from other situations by currents, storms, &c. In the muddy sub-pelagic bottom of the channel of Corfu, in the Ionian Islands, many of the thin-crusted and silky-spined spatangidæ are found, together with nuculæ, tellinæ, corbulæ, and other organisms fitted for such a habitus; but these are combined with abundant exuviæ of other organisms foreign to such a habitus,—as the valves of strongly-ribbed cardia, pectens, &c. In the one case, the shells, &c., are generally perfect or alive; in the other, more frequently separated and injured; and when in bivalves they are still connected, they are often found wide open and even twisted. These remarks will doubtless recall to the Geologist many similar cases in the deposits of ancient worlds.

3. In every petrographic class of deposit two sets of organisms may be expected to occur: the one suited to the habitus afforded by its geognostic position, and therefore the truly characteristic organisms of that class of deposit, or those which should be used in any comparisons between it and the same class when occurring again in the same or in any other formation; the other, extraneous organisms, the absence of which in the same class of deposit, at some other locality, would not be evidence of its geological difference, but simply of its freedom from the modifying influences which had affected the first locality.

There are many other geological facts on which much light is, at least, thrown, if they are not fully explained, by this method of comparing the conditions of zoological existence at

ancient epochs with those of the present, such as the abrupt terminations of peculiar petrographic deposits, the local distribution of fossils, &c., cases which can be observed wherever a mud or other bank is cut off by a current, or where a local deposit is formed under the lea of projecting rocks, or the shelter of a coral reef; but it would be vain to attempt to note them all, and enough has been said to guide the observer to a right mode of geological inquiry in tracing out any particular formation in its lateral extension. When the inquiry is made in a vertical direction, or by the aid of natural and artificial sections, the observer will find the same classes of deposit recurring at different intervals, and will discover a similar analogy in the assemblage of organisms connected with them; an analogy, such as similar conditions of existence must produce, —not an identity, which could alone spring from identity in the organisms of the two periods. He is thus led to another geological rule or principle.

4. Similar variations in the conditions of organic existence must produce similar modifications in the assemblage of organic beings existing at the same epoch in the various places subjected to such variations. Want of identity, therefore, in the organisms of the same petrographic class of deposit, as it recurs in successive portions of a section of any part of the earth's crust, cannot be explained by a variation of the conditions of existence, the petrographic and geognostic *identity*, combined with the zoological *analogy*, showing that the conditions were really the same, but must be ascribed to a difference in the aggregate fauna and flora of the epoch: or, in other words, it proves that the organisms of the strata, compared together, were connected with distinct acts of creation, or formed parts of distinct organic systems or worlds.

As the shell or skin of the animal is thus related to the petrographic condition of the deposit in which it is found, so must the animal itself have been formed to exist under the physical forces which gave rise to that deposit, and its general organization in like manner have been suited to all the circumstances

of its destined habitat. Temperature and pressure are two of the forces which most materially affect organic existence, and restrain or promote the distribution of organic bodies; but it must be first asked in what manner the stream of organic life commenced. The earliest historical record of the human race describes a local creation; and though the learned dispute as to the precise time involved in the events there noted, the Mosaic account is in favour of the theory of a centre of creation: and if the past worlds of former geological epochs be also taken into consideration, the more general principle of centres of creation may be safely adopted as more conformable to the simplicity of nature, than a contemporaneous or even a successive creation of the same species at various and distant localities.

A group of animals being created with organizations suited to certain conditions, such as the breathing of air or water, the capability of supporting a certain degree of heat or amount of pressure, when the mandate was pronounced that they should multiply, their lateral progression on the earth would be controlled by the laws implied by those conditions. In this way the course of the marine mollusca might be traced laterally along the coast at the depth suited to its structure and habits. But life is not the only active force; the tidal wave and the great marine currents are in motion; the sea beats against the shore, and the detrital matter of the rocks is carried forward and deposited in new strata, by which the shallow water is made dry land, the deep water shallow, and the advancing mollusc is thus impelled, by the necessity of keeping at a definite depth, to pass from the surface of one bed to that of another; and it may be readily conceived that, the general conditions remaining the same, species have thus lived over a space of time during which a long series of deposits have been formed, and in consequence that the fossil relics of such species should be found through an extensive range of geological strata. This combined lateral and vertical extension requires time, and it may be therefore generally assumed, that those fossils which

have the greatest vertical range, or have existed for the longest time, have also had the greatest extension in space.

Heat is the other great regulating cause, and it confines the extension of the land animal within narrow limits. If fitted to a temperate climate, he must seek it as he advances southward on higher ground; and as the mountains of the earth are comparatively small, his range is limited, and his progress or extension soon stopped. In marine animals the case is different; but it is necessary first to explain the conditions as to temperature of the ocean. It has been stated that the temperature of the earth increases in proportion to the depth below its surface: in the sea it is the reverse, as the temperature *decreases* with the depth, even at the tropics, until it has arrived at a very little above 32°. This to many will appear a contradiction, but it is not so: the outer crust of the earth is cooled partly by radiation, as on dry land, and partly by radiation and transmission on land covered by sea; but the passage of heat is slow through the earthy materials of the upper crust, whilst it is rapid through the aqueous covering; and it is therefore quite accordant with the laws of nature that the earth at the bottom of a sea many miles deep should be icy cold, whilst at a similar depth in the solid matter of the earth, the heat would be sufficient to melt iron. Even in the tropics, as the sun's rays act but feebly on the water, and can have very little heating effect on the ground at great depths, the temperature could not there exceed the mean temperature of the place, even if no interchange of water took place, except from below upwards, and *vice versâ:* but this is not the case, as there must be a gradual move of the water of a mean lower temperature southwards, until a general mean temperature had been attained, except in the mere superficial portion subject to the local influences of heated land, that portion being deeper as it is nearer to the tropical or more heated regions. The very careful experiments of M. Ch. Martins in the corvette *La Recherche* are perhaps the most interesting on record. They were made in the Polar Seas, in

the months of July and August of the years 1838-9, and extended to the depth of 870 metres (2784 feet), giving a uniform decrease of $1\frac{1}{4}°$ Fah. for 320 feet, or ·69 cent. for 100 metres, the final temperature arrived at being very nearly 32°. Parry and James Ross found the temperature lower, as it was only $28\frac{1}{2}°$ at the depth of 2304 feet in July, 1827. The equalization of temperature is further assisted by the flow of the heated equatorial waters towards the Pole, as the Gulph Stream, notwithstanding the doubts entertained by some on the subject, is traceable, according to M. Martins, to the North Cape. This uniformly low temperature of the depths of the ocean must materially restrain the dispersion of animals suited to a high, and favour that of animals suited to a low temperature, and thus explains many of those anomalies which occur in the habitats both of recent and fossil species. But the bottom of the ocean is not only affected by the deposition of fresh mineral matter upon it; it is subject to all the disturbances of elevating forces, and it is therefore highly probable that the progress of animal extension is at one point stopped by the elevation of the bottom, so as to bring it within the influence of a temperature too high for the existence of the organisms then living upon it, and at another promoted by a depression of the bottom, or *vice versâ;* and in this way various modifications of the groups of organic beings, and many of the abrupt terminations of them, must have been effected at all periods of the earth's history. These principles serve as a guide in any investigation of the topography of the ancient world; for example, as pressure, independent of temperature, must act as a limiting force, it cannot be supposed that even the mollusca could be distributed without the aid of banks or shoals, and air-breathing animals of the class mammalia without a continuity of land. The great development of the earlier fossiliferous strata implies therefore a former continuity of at least the ancient shoals, and Australia becomes therefore, to a certain extent, connected with Europe at the epoch of the carboniferous deposits. Ascending to newer

deposits, the oolites of Europe in the relics of marsupial animals, in the remains of fishes analogous to the Port Jackson cestracion, and in the still more remarkable occurrence of the genus trigonia, still existing in Australia, afford a striking correspondence with the present fauna of that portion of the globe. Is it not therefore probable that Australia, in which alone this type of the oolitic zoology has been preserved, was at that epoch connected with Europe by dry land, as in the carboniferous period it was by shoals? or may it not be possible that some of the mollusca of the carboniferous epoch, as well as its plants, which are associated with oolitic types of plants in the Australian coal-field, arrived there by combined lateral and vertical extension at a geological epoch posterior to that of the coal formation of Europe? In the tertiary periods, or those immediately antecedent to the present, many examples may be traced of continuity of land now no longer existing; and Geology is thus enabled to interpret the great changes which have taken place at successive epochs, and to represent, as it were, the various phases of the globe amidst all its changes. It is thus that Palæontology becomes a branch of the highest philosophy, and enables the searcher for truth to clear away those clouds of uncertainty and that confusion which, though only seeming, sometimes interferes with its perception.

CHAPTER VI.

General and Practical Remarks on Geological Formations.

In studying a geological formation, the observer will meet with evidences of each description of formative process, the natural history of the earth implying an investigation of the condition of its mineral and organic condition at each successive epoch. To express this relation between the eruptive, metamorphic, and sedimentary rocks, a compound nomenclature has been proposed by Sir C. Lyell, which should express at once the epoch of original deposition and that of metamorphism, as Ante-Cambrian carboniferous metamorphic strata, triasic oolitic metamorphic strata, &c., by which it is meant to be stated that the strata were respectively deposited prior to the Cambrian, and during the triasic, but reduced to their metamorphic condition by forces acting during the carboniferous epoch in the first place, and the oolitic in the second. The same principle of nomenclature has also been applied to plutonic or massive crystalline rocks and volcanic rocks, so that there may be Ante-Cambrian plutonic, Silurian plutonic, carboniferous plutonic, triasic, oolitic, cretaceous plutonic, &c.; and, in like manner, Silurian volcanic, carboniferous volcanic, triasic, &c., up to the volcanic rocks still forming. Though it is difficult in some, and indeed in very many cases, to determine with certainty the actual epoch of the original condition, or of the metamorphic change, of the crystalline schists, and also of the upheaving and apparent partial eruption of the plutonic rocks, or even of the eruptions of volcanic rocks, there cannot now be a doubt that the proposed nomenclature represents a correct principle.

The formations now recognized by all Geologists are exhibited in a descending order in the accompanying Table.

Table of Comparative Thickness of Fossiliferous Strata or Formation.

Class.	Order.	Group. Marine.	Group. Fresh-water.	Germany, by Cotta. Feet.	England, by Phillips and others.
	Recent. Post-Pliocene, or Glacial.	Erratics. Gravel, sand, and mud.		100	
Tertiary.	Pliocene, old and new. Miocene.	Marine.		80	1248
	Eocene.		Fresh-water.	300	99
				Total . . . 380	1347
Secondary.	Cretaceous, excluding the Wealden, which forms the next class.	All marine.		1800	1080
	Wealden.		Fresh-water.	Westphalia 600 Saxony 30	900
	Oolitic, or Jura Limestone.	All marine.		400	1350
	Lias.	All marine.		200	
	Trias, or new Red Sandstone.	All marine.		1500	900
	Permian, including Magnesian Limestone and red Conglomerate.	All marine.		1650	300
	Carboniferous, without old Red Sandstone.	Mixed marine and	Fresh-water.	600	2100 to 3000
	Devonian, or old Red Sandstone.	Marine.		From 150 to 10,000	Variable many thousand.
				Total . . . 16,750	
Primary.	Silurian. Cambrian.			Cotta unites these in one formation. Total 6000	Many thousand feet.

According therefore to Cotta, the total thickness of stratified fossiliferous deposits may be assumed as 22,750 feet, or about $4\frac{1}{4}$ miles, exclusive of the variable and uncertain deposits of the existing period: such estimates can, however, be considered only very rough approximations, as the thickness of each deposit may be expected to vary in every locality, and to undergo very material modifications both in the character and in the proportions of its several parts.

In the remarks on these formations the descending order

will not be followed, but the lowest recognized strata will be first noticed, and each successive formation, growing as it were one out of the other, will in order come under review.

CAMBRIAN, THE EARLIEST KNOWN FOSSIL DEPOSIT.

This term has been applied by Professor Sedgwick to the stratified rocks which occur in Cumberland, North Wales, and other places, for the most part slaty, and without fossils, under the decidedly Silurian strata. They contain but a small proportion of lime, and their fossils are local and rare; nor as yet has sufficient evidence been obtained to place them in a zoological order distinct from that of the Silurian. The apparent thickness of the slaty and gritty beds is considerable, but it is highly probable that they are repeated by contortions. The prevalence of the slaty character shows that the progress of formation has not been varied by much original disturbance, and the depths of its beds indicates the probability of some portion having been a deep-sea, or rather semi-pelagic deposit. The view now taken by Professor Sedgwick is, that the Cambrian can no longer be considered a system, but a distinctly marked group in the Silurian, the Cambrian group at the base of that system.

SILURIAN.

This formation, since the publication of the splendid work of Murchison, has attracted the marked attention of Geologists, and exhibits the relics of organic beings in great abundance, and of very peculiar forms. It has been rescued from the formerly obscure regions of the grauwacke, and reduced to light and order by the discoveries and research by Sir R. Murchison and his followers. The lower group of this order includes the Llandeilo flags, and above them the Caradoc sandstone, the former being micaceous slaty grits. The next in order ascending is the Wenlock group, consisting of a deep bed of shale, surmounted by a bed of limestone; and the third or upper, the Ludlow, comprising the lower Ludlow shale, the Aymestry limestone, and the upper Ludlow, a

calcareous grit or sandstone. In England these groups follow each other in actual sequence of superposition, and are therefore distinct in order of time. But it must not be supposed that in every other region the same precise sequence is exhibited, for such would be contrary to the ordinary laws of geological deposit. In Norway and Sweden there is a similarity in lithological character, and the conditions of deposit have been nearly the same; but in many parts of North America the limestone has been developed much more extensively, and the condition of deposit was therefore different.

In this formation, including the Cambrian, the earth first exhibits itself as the theatre of life, and we find the remains of fish, strange in form but high in organization, as the genera onchus and plectrodus, many mollusca, including peculiar forms of the brachiopoda and cephalapoda; very characteristic crustacea, belonging to the extensive family of trilobites, which, beginning to exist at this early epoch, flourished in number both of species and individuals, and then rapidly passed away, the family being traced no farther than the carboniferous order; radiata, rare; zoophyta, less abundant than in succeeding orders, but exhibiting some peculiar forms. In respect to the conditions of deposit, it may be observed, that though the extensive limestone deposits of this epoch, adjacent to the great lakes of America, were probably pelagic, the large orthoceræ having been well suited for deep seas, the general evidence afforded by the fossils of England and Ireland, particularly by the trilobites, the flat brachiopoda, as orthis, leptæna, lingula, &c., the many species of nucula, and even it may be added by the fish as they were probably fitted to grovel in the mud, is in favour of muddy and sandy deposits in moderate and sometimes shallow depths; and the beds of limestone have probably here, as in the similar instances of the carboniferous system and even of the recent epoch, originated in an accumulation of the remains of testacea, the temporary cessation of the influx of mud, and the growth of corals suited to such habitats.

It would be impossible to bring forward all the peculiarities

of the many remarkable fossils of this formation without entering largely into their natural history; nor in the present case is it necessary to state what fossils characterize the subdivisions or groups of the formation: it is enough, in a practical point of view, to be able to recognize the existence of the formation itself; and this is of much importance, as it is below the great carboniferous system on the one hand, whilst on the other it overlies a series of metamorphic rocks, embracing the useful deposits of various descriptions of slate and other building stones. The invertebrate fossils which have not hitherto been discovered in any more recent deposit, excepting in some instances in the Devonian, are graptolites, which are curious zoophytes, supposed to be related to the pennatula; the chain coral, catenifera escharoides; the genera remopleurides, phacops, calymene, asaphus, ampyx, trinucleus, harpes, brontes, and several others of trilobites; of the brachiopoda, the genus pentamerus; of the cephalopoda, the genera phragmoceras and lituites; and of the gasteropoda, the ecculiomphalus.

Many of the schistose beds yield good flags and slates.

Besides the northern localities of Europe and America, the formation has been noticed at the Falkland Islands, and in South America, and recently in Portugal, where it is associated with coal-bearing strata which conform in their plants to the carboniferous type.

DEVONIAN, OR OLD RED SANDSTONE.

This order, so long known under the name old red sandstone—a term nearly as obscure as that of grauwacke—has been recently, by the researches of Professor Sedgwick and Sir R. J. Murchison, aided by the labours of Sir H. De la Beche and Messrs. Phillips and Lonsdale, raised to the rank of a distinct fossiliferous formation. Accustomed, as sandstone and conglomerate, to be viewed in the light of a drift, it appeared difficult to connect it with the limestones of Devonshire; but when similar limestones were found on the Continent in similar positions, the limestone of the Eifel being thus

placed, this difficulty was removed, and the formation was proved to embrace the usual assemblage of argillaceous, sandy, and calcareous strata. In Scotland, and on the borders of Wales, the formation is exhibited in its original character of a red sandstone and conglomerate with shale and marl; the conglomerate and sandstone at the top, the variegated marls and impure concretionary limestone (cornstone) in the centre, and variegated micaceous or quartzose sandstone (splitting into tiles, tilestone), below. In the lower division, in the North of Scotland, many peculiar forms of fishes have been found, whilst in the upper, comprising the belt of yellow sandstone, the genus holoptychus appears, which extends into the carboniferous order. Were this portion of the system alone studied, it would lead to its connection with the carboniferous rather than with the Silurian, and it is still so placed by Cotta; but when the Devonshire and Cornwall strata are examined, and compared with those of the Eifel, the presence of species common to the Devon and Silurian on the one hand, and to the Devon and carboniferous on the other, impress upon them a different character. Professor Phillips, in consequence of this mixed distribution of fossils, has proposed to embrace under the general term palæozoic, the Cambrian and Silurian as the lower palæozoic, the Devonian as the middle palæozoic, and the carboniferous as the upper palæozoic, to which Sir R. Murchison has added the permian or magnesian limestone. Of 275 species in the Devonian strata of Devon and Cornwall, Professor Phillips states that 25 have been found in the lower division in England, 51 in the upper division in England, and 57 in the Eifel and Bensberg.

The very dilapidated condition of many of the fossils of this formation leads to the belief that they were only present in the deposit by the influence of drift: the trilobites and other distinguishing bodies of the Silurian epoch, which are described by Professor Phillips, are almost all in a shattered state. If then these fossils, and many of the zoophytes, &c., are present merely from drift, it is not impossible that they

were living in greater abundance elsewhere at the time of the deposition of the Devonian strata, and that the actual zoological relations were closer between the Silurian and the lower Devonian, than would be inferred from these fragments of fossils alone. Professor Phillips seems also to adopt this opinion, that the analogy between the lower Devonian and the Silurian is considerable, whilst a similar analogy prevails between the upper Devonian and the carboniferous. Cotta still classes the Eifel beds with the Silurian; but it cannot be doubted that if Silurian, they occupy a higher position in the series than any of our English or Irish beds, and must therefore be parallel, as shown by our English authors, with the lower Devonian.

In referring to this use of fossil evidence it is well to bear in mind, that any fossil species of an early epoch may be continued upwards into more recent formations, and that the appearance of a small number of such fossils cannot therefore alone be considered sufficient to place the strata containing them in the older formation: it is in the general grouping and arrangement, under the same petrographic characters, that confidence can be placed. The appearance, on the contrary, in any bed, of fossils known to be abundant in, and characteristic of, a recent formation, must always be strong presumptive evidence against its antiquity.

Practically, many beds of this formation, especially of the yellow sandstone, are excellent building stones; whilst the decomposition of its marly beds produces a rich productive soil. The limestones are valuable both for building stone and lime. In Russia, south of Petersburgh, a large area, formerly supposed to belong to the new red sandstone, is of this geological age, though abounding in saliferous and gypseous beds;—a remarkable fact, being another proof that salt deposits have, in very similar circumstances, been formed at various geological epochs. The determination of this formation is important, as it underlies the coal, and in Spain coal-bearing strata are associated with it.

CARBONIFEROUS.

This formation, the most important of all in its economic characters, is a vast assemblage of calcareous, arenaceous, and argillaceous strata. If it be considered that the great masses of limestone were formed in deep seas, whilst the coal shales were formed in estuaries, and in some cases in lakes, it is evident that where the limestone division prevails, the shales may be expected to diminish, and to lose their estuary character, so that coal will become less abundant. This is the case in Ireland, and accounts for the comparative scarcity of coal in that country.

The great limestone deposit which forms the basis of this system has been called the mountain limestone, and is characterized by many peculiar fossils: in the South-west of England, in Somersetshire and South Wales, it is strongly marked, and is separated from the coal measures above by a thick deposit of arenaceous strata; but in the North of England, the coal descends into the millstone grit, and even alternates with the upper beds of the mountain limestone; and in Scotland, this mixture of marine strata with those containing coal is still more marked. In Ireland, many of the masses of the mountain limestone are separated into distinct beds by shale, which, not being associated with coal, were probably also deposited in tolerably deep water, as in the Mediterranean: the coral living at the bottom of its waters is subject to be covered over by the mud moved along by the currents.

The presence not merely of a vast variety of terrestrial plants in the coal shales and grits, but in some cases of fresh-water fossils, such as the genus cypris, has led to the belief that some of these deposits have been lacustrine; but whether formed in actual lakes, or at the mouths of rivers occasionally dammed up, and formed temporarily into fresh-water lakes, cannot be determined. The fossils of this formation are very characteristic: in the plants, so rich in various forms, resembling the tree ferns of the tropics, there is evidence of

a climate resembling that of our most Southern regions, and this is confirmed by the great abundance of sauroid fishes, and of cartilaginous fishes of the families of squalidæ and raiidæ. The crinoids are largely developed, as well as the corals, many of which are lamelliferous, as in coral reefs now forming; and in studying this formation zoologically, it is necessary to attend to the difference of habitat of corals, many being confined to reefs, whilst others live in shallow water on the coast and are frequently enveloped in mud. The genus productus abounds.

That coal is the product of ancient vegetation entombed in mud and sand, and in the course of ages reduced to its present state by chemical change, cannot be doubted; but consistently with such conclusion it might be assumed either that the plants grew where the coal now exists, or that they had been washed down into estuaries, and there accumulated, or that the coal was the product of a bog or peat moss,—an opinion supported by microscopic investigation. It is highly probable that each of these theories is correct in certain localities, and in either case the alternations which must have taken place are very remarkable: for example, in the North of England, the total thickness of the coal-bearing strata may be estimated at 3000 feet, whereas the coal itself is arranged in many layers or seams, the total thickness of which does not exceed 60′, whilst the thickness of the seams varies from a few inches to 6′ or 7′. In the Newcastle district, counting the minute seams, there are forty layers. At Dudley there are eleven, of which one is 30′ thick. In South Wales there are twenty-three beds exceeding 1′ 6″ in thickness, besides many others, the total thickness of workable coal being 95′, equal in mass to many hundred million tons of coal. At Mons there are 115 workable seams, few of which exceed 3′ thick. Besides the Irish and Scotch coal fields, England and Wales possess the following coal basins: Northumberland and Durham, Yorkshire, Staffordshire, Lancashire, Whitehaven, Warwickshire, Shropshire including Coalbrook Dale, North Wales,

South Wales, some of which may be subdivided into other basins.

Such masses of vegetable matter, composed of plants long since passed away from the living world, of which more than 300 have been figured and described, 200 belonging to the order of ferns, and others to giant mosses and to cellular plants, exhibit peculiar conditions of organic life. Some of these conditions have been repeated, though in a fainter degree, at subsequent epochs, and given rise to limited carbonaceous deposits; but as the various changes, physical and and organic, working in the earth's crust, advance towards the present state of things, an approximation to the conditions now observable, and a receding from those which once so greatly promoted the growth of succulent plants, are in strict accordance with the laws of nature. As the influence of central heat diminished in its progress southward, successive portions of the earth may have become fitted, though in an inferior degree, for the support of such plants, and partial deposits therefore appear at such epochs; nor should it be forgotten that when the Polar regions were first brought by the diminution of central heat to the proper temperature, they were, from the deficiency of solar heat, better fitted for such vegetation, the temperature being equable and unattended by the scorching effects of the sun's rays now felt in Southern regions. The seams are sometimes extended over a wide space, but the general character of a coal deposit is that of a basin, and the phenomenon of faults is strikingly exhibited, the seams being sometimes thrown up or down several hundred feet. Some faults are accompanied or caused by dykes, but in other cases they appear to be simple dislocations attended with slips. The knowledge of the various forms of such faults, and of the direction in which the suddenly lost seam should be sought, constitutes one of the most difficult points in mining science.

Dr. Ure gives the following Table of the quantities of coal exported from the several ports in England, Wales, Scotland,

and Ireland, in 1836 and 1837, an exportation which has since vastly increased.

	1836.	1837.	Increase.
	Tons.	Tons.	
England and Wales	6,757,937	7,570,254	812,317 or 12·02 per cent.
Scotland . . .	624,308	626,532	2,224 or 0·36 „
Ireland	7,027	7,515	488 or 6·94 „
Total . . .	7,389,272	8,204,301	815,029 or 11·03 per cent.

In Fuller's time (1661), 200,000 chaldrons were imported annually into London, but now the consumption is nearly 3,000,000 tons, which is brought into port in about 9700 ships. The annual quantity raised was estimated at 15,500,000 tons by Mr. Taylor, and Durham and Northumberland, he considered, could have met that demand for 1700 years. Mr. R. C. Taylor estimates the whole British production at more than 31,000,000 tons per annum. The French Mining Reports state that coal is raised in thirty departments of France, in which 258 mines are in operation, and 21,913 workmen employed. In 1814, the quantity raised was 665,000 tons; in 1825, the quantity had doubled; in 1832, the produce was 1,600,000 tons; in 1836, it amounted to 2,500,000, and it is now more than 4,000,000 tons.

Cotta has given (1839) a comparative statement of the coal produced in the several coal districts of Europe, which is valuable for comparison:

	Tons.		Tons.
In England . . .	20,769,231	Brought forward	30,753,233
Belgium . . .	5,215,385	In Sweden and Norway	28,293
France . . .	2,215,385	Hanover . . .	21,646
Prussia . . .	1,569,231	Spain	18,462
Russia . . .	738,461	Both Hesse . .	15,231
Austria w[th] Bohemia	184,616	Sardinia . . .	4,662
Bavaria . . .	32,308	Weimar . . .	1,939
Saxony . . .	28,616	Portugal . . .	415
Carried forward	30,753,233	Total . . .	30,843,881

Mr. R. C. Taylor states the production of the United States

as about 4,500,000 tons. Dumas, in 1828, gives the following values of the coal produced:

	Francs.		£.
England	90,000,000	=	3,562,500
Low Countries, including Rhenish Provinces and Luxemburg	37,000,000	=	1,464,583
France	12,000,000	=	475,000
Russia, Silesia	3,600,000	=	135,000
Hanover and German Confederation	3,600,000	=	135,000
Total			5,772,083

The product of the British coal fields is more than double that of all the rest of Europe; and the gross value of the collieries of Great Britain and Ireland cannot be estimated at less than £ 9,000,000 sterling.

But this is not the only valuable product of the formation. The argillaceous carbonate of iron, or clay ironstone, which is the principal ore of iron used in the British Isles, occurs in beds in the coal shales, thus putting in contact with each other the mineral ore and the fuel for smelting it. In 1826, the quantity smelted into cast iron was between 600,000 and 700,000 tons; and as there had been a steady increment up to that time, which must have gone on during the last few years with at least an equal intensity, the present quantity cannot be estimated at less, stated in round numbers, than 1,000,000 tons of bar iron, being in value equivalent to £10,000,000 sterling. In France, there are iron works in sixty out of the eighty-six departments. The number of establishments in 1836 was 894, and of workmen 15,738, the product being 303,739 tons of pig iron, and 201,691 tons of bar iron, valued at £ 3,580,000.

Nor are these the only resources of the formation. The mountain limestone, which exhibits in its layers of silicious or chert concretions a strong analogy to the subsequent pelagic deposit of the chalk, is in England the source of much mineral wealth, and produces more than one-half of its lead. The proportion due to this formation cannot be assumed as less

than 26,000 tons, equivalent to about £520,000 sterling; so that, from this formation alone, mineral wealth is annually produced in Great Britain to the amount of nearly £19,000,000 sterling; and in addition to this direct production, its indirect importance as affording the means of smelting the ores of other metals, such as copper and zinc, is forcibly illustrated by the extensive works of Swansea, to which ores of copper are brought from all quarters of the globe. And to this should be added also the value of the lime and marbles, or other building stone, produced from the limestone, and of the excellent building stone which is obtained from many of its grits, as in the neighbourhood of Glasgow, the beauty of that city being due to the ready acquirement of such excellent materials. And if the mind passes from the crude or simple value of the materials themselves to the contemplation of the vast results proceeding, in further stages of production, from coal and iron as used in the machinery of its manufactories and railways, it discovers in the possession of so large and productive a portion of this formation, the source and foundation of the commercial, and, in consequence, of the political greatness of Great Britain.

Great Britain has in her colonial possessions of New Holland another coal formation, which has been supposed to belong to a more recent epoch, though it is highly probable that the peculiarity of some of the plants only implies the commencement of that isolation of type which now distinguishes that country. The coal of the East Indies is also supposed to be more recent than the true coal formation.

In America there is a formation both of blind and bituminous coal, within the limits of the United States, greatly exceeding in extent our British coal fields, likewise in Nova Scotia, at Picton, and Cape Breton. China and Japan are supposed to possess extensive deposits, and coal occurs in Borneo and Labuan. Such then is the lateral distribution of this valuable mineral formation; and, as regards its position vertically, it is very variable, many of the seams at Newcastle

being worked under the sea, whilst at Chipo, which rises above the plain of Santa Fe de Bogota, it is found at 8000 feet above the sea, and at Huanoco at 12,800 feet, or at the limits of eternal snow.

PERMIAN, INCLUDING MAGNESIAN LIMESTONE.

This formation, including its underlying red conglomerates and sandstones and marls, is important as immediately overlying the carboniferous. In the South-west of England, its strata are unconformable to those of the carboniferous system; but in the North-east they are conformable to and seem to form part of them. In all formations, cases of this partial conformability between the upper and lower may be expected to occur, according as the disturbing movements are more or less extensive or local; and it was therefore necessary to determine the great geological divisions from a general and not from a partial examination. Though the sandstones strongly resemble the new red sandstone, the fossils of this formation closely approximate to the carboniferous, the genera producta and spirifer of the brachiopoda occurring in each; and the genus palæoniscus of fishes, though this remarkable genus is extended into the new red sandstone, as palæoniscus catopterus occurs in profusion, associated with posidonomya minuta, huddled together in a small patch or pool of the sandstone and marls of Rhone Hill, county Tyrone. On the other hand, the spirifer undulatus (Sow.), supposed a characteristic species of the magnesian limestone, occurs in Ireland in beds which are overlaid by apparently well-marked carboniferous limestone. On the Continent, the name 'rothes todtliegendes' has been given to the lower red conglomerate, to distinguish it from the white grits which immediately underlie the kupferschiefer or copper slate, and which sometimes also contain copper ore, which the red-*dead*-lyer does not. In England, the copper slate and the white grit do not exist, and the lower red sandstone and conglomerate immediately underlie the magnesian limestone: Cotta places it in the carboniferous system, making

the white grit the base of the magnesian limestone formation. In the South-west of England, drift or conglomerate beds prevail, exhibiting, however, the peculiarity of a dolomitic or magnesian limestone paste: in the North-east, a yellow magnesian limestone, passing upwards and downwards into marl slate and marl with gypsum. On the Continent, the zechstein is a dense, and sometimes porous, grey, generally fetid magnesian limestone, connected upwards with marls containing many extraneous substances, such as ironstone, gypsum, and rock salt, thus approaching to the character of the true new red. The copper slate of Mansfeld has a thickness varying only from 1½ ft. to 2 ft., and is worked in numerous establishments by a most difficult process, called there krummhölzerarbeit, or crooked-stick work, the miners crawling and working in low cavities, only 18 or 20 inches high, lying upon their sides, and being supported by pieces of bent timber or crooked sticks. In England, the formation is practically important from the excellent building stone which some of the magnesia beds afford, the tint being specially favourable for Gothic buildings. York and Beverley Minsters are favourable examples of the stone, but there is great difference as to durability, according as the more purely magnesian limestone or the gritty beds have been used. This stone has been selected for the New Palace of Westminster as the best building stone of England. The permian system is magnificently developed in Russia.

The class of reptiles begins in this formation, it being still doubtful whether it can be said to occur in the carboniferous.

NEW RED SANDSTONE OR TRIAS.

This formation, from the prevalence of a variegated character in its sandstones and marls, has been sometimes called 'poikilitic.' On the Continent, where its several members are better developed than in England, it has received the name of 'trias,' as divisible into three great sections. The lowest of these is the 'bunter sandstein,' or variegated sandstone, which is distinguished by greenish stripes and spots, and con-

tains clay galls; it is associated both above and below with variegated red and green marls, containing both laminated and fibrous gypsum, and rock salt. As the muschelkalk, or central division, is deficient in England, and gypsum and rock salt occur on the Continent in the marls, both in the upper and lower division, it is difficult to decide generally whether our salt-bearing strata belong to or should be separated from the more decided sandstones and conglomerates which underlie them. The white sandstone of the Vosges, supposed to belong to the lower or variegated division, is placed by Sir R. Murchison in the permian: it is a valuable building stone.

In Thuringia and Swabia the muschelkalk division is fully developed, the limestone under several forms or varieties alternating with marls and clays which sometimes contain gypsum and rock salt, and is occasionally dolomitic.

In the upper division or keuper, marls and clays prevail, though still associated with sandstones. Gypsum and rock salt still occur, and sometimes an impure coal. As fossils are extremely rare in the sandstone divisions, it was scarcely possible to allocate to their proper place in this triple system the English beds; but the fossils of a dark marly stratum which occurs at Axmouth, and on the banks of the Severn in Gloucestershire, and is called the 'bone-bed,' have been proved to belong either to the keuper or muschelkalk: they are, Hybodus plicatilis, Saurichthys apicalis, Gyrolepis tenuistriatus, G. Albertii,—of which it is very remarkable that Saurichthys apicalis, Gyrolepis Albertii, G. tenuistriatus, have been also found in a seam of calcareous grit connected with black shale in an equally local deposit on the face of Ben Evenagh, at Lisnagrib, county of Derry, the Acrodus minimus, another muschelkalk fossil, being there added to the list. It may therefore be reasonably inferred that though the muschelkalk is not fully developed in the British Islands, two members of the series are certainly present, with a trace of the other.

The remarkable foot-prints of an animal, to which the name chirotherium was given, should be noticed. Various conjec-

tures as to their nature were hazarded, but Mr. Owen has recently proved that they were formed by the animal which, from the nature of its teeth, he had named labyrinthodon, and which he has further proved to belong to the batrachian order, or to be a gigantic frog. The ammonites, a genus of the cephalopodous molluscs, here first appear; and in the flora as well as fauna there is a striking difference from the underlying strata, the species of forty-seven genera noted by Professor Bronn being quite distinct.—*Footsteps of supposed Wading Birds observed in America.*

In England, this formation is the depository of rock salt. In Cheshire, the alternating beds of red and green marl with gypsum and rock salt sometimes exceeds 600 feet in thickness; and at Northwich, the two beds of salt are at least 60 feet in thickness, and extend laterally for 1½ miles. In Ireland, the gypsum prevails more than the salt; but even there, on the line between Belfast and Carrickfergus, there is reason to believe that salt may be found. And generally this curious connection of the sulphate of lime with the chloride of sodium deserves attention, as affording a probable indication of the occurrence of salt in other formations. The average quantity of salt manufactured in Cheshire may be stated at about 250,000 tons annually. The celebrated salt-mines of Wieliczka, in Galicia, belong to the cretaceous formation.

LIAS ORDER.

In this formation argillaceous matter or clay preponderates, being associated with argillaceous limestone, marl, sandy marl, and sandstone, and it is remarkable as the great locality for marine reptilia; for although the genus icthyosaurus had already appeared in more ancient deposits, it seems to have attained in these its full development, and is accompanied by the equally curious genus plesiosaurus. The existence of a marine saurian amidst the Gallapagos Islands, as noticed by Dr. Darwin, is highly interesting, as exemplifying the probable mode of existence of these vast animals, and the conformability

of their habits with those of the crocodile. That curious genus of cephalopodous molluscs, the belemnite, also first appears here, and the gryphæa, a genus of the family of oysters, is abundant; the presence of such animals establishing the marine origin of the deposit, and confirming the fact that marine saurians were, at that early period, swimming in multitudes around the muddy shores of the then existing land. The characteristic colour of the limestone, which sometimes assumes a riband-like arrangement amongst the argillaceous beds, is blue, but there is occasionally a white variety, and in some instances sandstone prevails in the lower members; as for example, in Würtemberg, where sandstones of brownish and yellowish hues are associated with marls and limestones in the lower lias, the upper being composed of dark lias shale and limestone. The lias shale of Würtemberg is so rich in a species of the genus posidonomya, the P. Bronnii, that it is even called the posidonian shale; and a similar occurrence of that genus in shales of the carboniferous period, and in marls of the new red, is highly illustrative of the general character of such deposits. Some thin beds of coal occur also in the shales, which, as well as the limestones, are strongly impregnated with bitumen, proceeding, it is very probable, from decomposing animal substances, such as fishes, &c., which abounded at the epoch of their deposition. Practically, the sandstones are sometimes sufficiently firm to be used for building, though they are apt to become iron-shot, or stained. The limestone is occasionally hydraulic, and the soil is generally fertile.

OOLITE OR JURA FORMATION.

The clays of the lias form the basis of the oolitic system, and in ascending into it, other argillaceous bands mark those changes in the conditions of deposit which are to be expected in every great formation, representing, as it must do, the variations of drift consequent on the changing direction of currents. These bands have, in England, led to a division of the oolites into lower oolite resting on the lias; the middle oolite resting

on the Oxford clay, which separates it from the lower oolite; and the upper oolite resting on the Kimmeridge clay, which is between it and the middle oolite: but it must be evident that such clay bands, being merely the result of local causes, cannot be expected to occur in all localities at the same epoch, or to produce a similar division in all countries. On the Continent, the formation has been divided into the upper and lower Jura, the upper being characterized by a light-coloured, whitish or yellowish limestone, which forms the great mass of the Jura Mountains, from which it has derived its name, and the lower consisting of roe-stone and dolomite, the latter being penetrated by holes or cavities, and of sandstone, marl, and clay. In the Jura limestone there are partings of hornstone, strongly resembling the flints of the chalk; and its surfaces exhibit also the very beautiful dendritic markings of oxide of manganese which equally resemble those of the chalk of Ireland. The Bavarian Jura formation is remarkable for the numerous bone caverns of its dolomites, and for the celebrated lithographic stone of Solenhofer. The wooded hills of Pappenheim are composed of a regularly stratified limestone arranged in thin horizontal beds. The stone is extraordinarily pure and dense, yellow or grey in colour, and, from the thinness and regularity of its layers, peculiarly fitted for lithography. The hills themselves are distinguished by their broken aspect and wall-like character, which makes them look like so many fortresses; and on entering the valleys, the ringing sounds of the true lithographic stone, as it is broken up for use, is heard on all sides. The layers used for this purpose are from 1 to 4 inches thick, and when they are still thinner, or are unfit, by containing fossils, for lithography, they become useful as roofing tiles, as door and window linings, as tables, &c., to which purposes they had been extensively applied long before the invention of lithography. These peculiarities of the physical features of the country, and of the mechanical characters of the stone, deserve to be remembered in looking out for good lithographic stone in other countries.

In addition to the defect consequent on the presence of large fossils, veins should be carefully avoided, as in printing they mark the drawing, however fine they may be, with white lines, and increase greatly the difficulty of reducing the surface to a uniform state. In the English oolites, the Stonesfield slate, lying at the base of the great oolite, a member of the lower division, is the most remarkable: it is a slightly oolitic limestone, and though only 6 feet thick, abounds in fossils. With impressions of ferns and other terrestrial plants, the elytra of beetles, and the remains of saurian genera already noticed, occur those of the pterodactyl or flying lizard, and what is still more remarkable, the jaws have been discovered of at least three species of mammiferous quadrupeds of the marsupial order,—partly allied to the opossum, and partly to the myrmecobius of Australia,—a singular analogy, at this early epoch, to a region still so widely distinct in its fauna from other parts of the world. In the lower division also occurs the Bath oolite, which is such an excellent stone for the delicate mouldings of Gothic architecture, and is represented in France by the Caen stone, which, being better fitted for the purpose, was imported by our early architects, as is seen in the beautiful Temple Church. In the middle oolite is the 'coral rag,' so called from the continuous beds of corals of which it is composed, and which still retain the position in which they originally grew. In the upper oolite is the celebrated Portland stone, so well known for its beauty as a building stone.

Many parts of this system are distinguished by a profusion of some particular fossil which is always characteristic of a regular deposit, as distinguished from a drift: such, for example, was the surface of the great oolite when studded over with pear-encrinites, which were afterwards buried by the irruption of the Bradford clay; the clays of the upper oolite with their oysters and gryphites (ostrea deltoidea and gryphæa virgula); the nerinæan limestone of the Jura, distinguished by the peculiar univalve genus nerinæa and the diceras lime-

stone of the Alps, so called from the abundance of the very curious bivalve genus diceras.

Although in this formation the great body of the fossils demonstrates a marine origin, the frequent occurrence of fragments of wood, the coal beds and bituminous shale which enter into the system, the many impressions of plants and insects, the abundance of saurians and of encrinites which may be considered more fitted for shallow than for deep waters, and, above all, the actual discovery of land animals, all concur in proving that the deposit was formed in the vicinity of land; and it becomes therefore an interesting precursor of the next formation, in which land was connected with a then existing lake.

WEALDEN FORMATION.

This formation, remarkable from its fresh-water origin, is not entirely destitute of marine fossils, and it has therefore rather the character of an estuary than of an inland lake. On the Continent, it has been associated with the cretaceous system; and as the lower beds of the green-sand correspond closely with some in this system, and the fresh-water beds are in France sometimes separated by marine beds, similar to those of the green-sand, this allocation may be considered correct. In England, the oolitic beds were first raised up quietly without any great disturbance, as the celebrated 'dirt-bed' of Portland, with its upright roots, rests horizontally upon them, the roots even penetrating into the subjacent oolite, and portions of the compound deposit were subsequently thrown out of the horizontal position, as appears in the section at Lulworth Cove. If the principal basin, in which these beds have been traced, extending at each end from France into England, be really continuous, the deposit, whether lacustrine or estuary, was very extensive, though much interrupted, formations of a different character being contemporaneously deposited within its area. These are problems of very difficult solution, as it is almost impossible to represent to the mind the actual condi-

tion of the earth's surface in respect to land, sea, and river, at each successive epoch of its history, darkened as it must be by the effects of reiterated changes and unceasing wear.

This vast estuary was subsequently exposed to the action of the sea, and the dry land existing either on its margin, or as islands within its precincts, was covered by the marine deposits of the cretaceous epoch, some of which indicate a subsequent depression of the land sufficient to have permitted deep sea deposits. Such oscillations are wonderful, and strongly contrasted with the comparative quiet which now reigns on the earth; but they are learnt from geological investigations, just as the facts, the habits and opinions of past ages are from historic records; and we owe therefore to this science the knowledge we now possess of changes which, without it, would have been unknown to us. In England, the base of the formation, which is more extensively developed than in any other country, is the well-known Purbeck limestone, distinguished by a profusion of fresh-water shells. The beds of limestone are separated by marls, and the conjoint thickness is about 250 feet, which is an immense depth for a fresh-water deposit. The Hastings sands with clays and calcareous grits succeed, and are about 400 feet thick, being equally extraordinary as a fresh-water drift; and the whole is covered by the Weald clay, with its thin beds of sand and shelly limestone, about 200 feet thick. This formation implies the existence for a long time of vast areas of fresh water resembling those of North America, in which at this moment, from the continued wear of their banks and the depth of their bottom, which in some cases is below the level of the sea, there can be no doubt extensive deposits must be forming. Mr. Robertson has recently proved the existence of Wealden beds at Brora, in Sutherlandshire, and advanced reasons for associating the Yorkshire oolitic coal also with this formation.

Equally developed fresh-water deposits can be traced in other countries; and it is evident therefore that a very large portion of Europe was once covered with fresh water. In

Westphalia, the Wealden is represented by a deposit 800 feet thick, consisting of sandstone and bituminous marl, with layers of coal and of ironstone and beds of limestone, the whole being characterized by fresh-water fossils. In Saxony, at Niederschöne, it is reduced to a deposit 40 feet thick, of dark-coloured sandy shale and marl, which is sometimes bituminous, and contains traces of coal, with an abundance of vegetable remains. Amongst these fossil plants only one shell has hitherto been discovered, but that is a most characteristic one, belonging to the fresh-water genus anodonta, which is confined exclusively to muddy lakes and pools. The quadersandstein, or green-sand, overlies this deposit, and Cotta thinks it probable that the beds of this formation in Silesia, which contain coal and the remains of plants, should also be allotted to the Wealden. Amongst the numerous reptiles of this epoch appear tortoises of genera which now occur in the fresh water of tropical regions. The iguanodon, so called by its discoverer, Dr. Mantell, from its analogy with the living iguana, was a herbivorous reptile, and appears to have abounded at this epoch. The nature of the fossil plants, and the number and magnitude of the reptiles, show that the climate still continued tropical. The Purbeck limestone is well known as lumachella marble, the designation lumachella being derived from the Italian word lumaca, a snail, and applied to those varieties of limestone which, with a granular or marble structure, abound in fossils. Caution is required in the selection of this stone, as some of its beds easily disintegrate; and in all specifications for its supply a sample should be referred to, in order to insure the delivery of the proper kind; a remark which is applicable in various degrees to almost every building stone. The sandstones, which are not durable, give rise, from their wear, to very picturesque scenery, as about Tunbridge. The clays produce a strong soil, as in the rich district of the Weald of Kent.

CRETACEOUS.

Succeeding to the extensive fresh-water formation of the Wealden, is a still more extensive and generally more widely diffused marine formation—the cretaceous. To bring this change more clearly to the mind, it may be well to imagine what would be the result, if, after ages of tranquil deposit of fresh-water detritus in the depths of the lakes of North America, a depression of the surface took place, by which it became, as the bottom of the lakes now is, below the sea level. Such a depression would cause, even if carried to a very moderate extent, an irruption of the sea over a large portion of the country, and marine deposits would immediately commence. If, again, after an accumulation of such deposits, equivalent in thickness to the cretaceous, the whole mass were uplifted by the action of subterranean forces, the fresh-water deposits might be brought to view by the fracture and removal of part of the marine covering, whilst the remaining part of that covering might continue as a mural boundary surrounding them. In such a case, a strongly analogous result to that of the Wealden and chalk would be produced. Commencing at its base, the cretaceous system is sandy, and this division has been named the green-sand formation in England, the quadersandstein formation in Germany,—the names pointing to the principal peculiarity of the sandstone in each locality. In each it admits of further subdivision into upper and lower, the two being separated in England by a deposit of marl and clay, called gault; in Germany by one of marl, marly sandstone and limestone (the plänerkalk). But though these divisions exhibit a striking conformity when viewed at particular localities (if, for example, the green-sand of England be compared with the quadersandstein of Saxony and Bohemia), considerable modifications appear in other localities. In Westphalia and North Germany, a conglomerate and a clay which Cotta considers the equivalent of the Specton clay occur below the lower quader: the pläner is replaced by a blue clay

with crystals of gypsum, corresponding still more closely with the English gault; the upper quader is represented by a green-sand, which is surmounted by bright red marl. The sand-stone of the Carpathian Mountains is also, as has been before noticed, referrible to this epoch. On the Continent, the upper limit of the green-sand is also modified, the same lithological character, in sandy marls and sandstones, extending in Westphalia and North Germany high up into the upper section of the cretaceous system; but these are only natural variations, being the necessary result of those local peculiarities which have already been so frequently adverted to. In England, the upper section of the cretaceous formation can be divided into the lower chalk without flints, and the upper chalk with flints, the whole reposing on the chalk marl,—a subdivision which is purely local. In Saxony and Bohemia, the whole section is reduced to beds of flints; in Westphalia and North Germany, the upper member is feebly represented, but all below it consists of chalk marls and sandstones, far more in character with the green-sand than with the chalk, of which it is proved to be equivalent by fossils. In France, the Maestricht beds are at the summit, resting on the white chalk with flints, and from their peculiarities have been considered by some Geologists an upper member, approximating the chalk to the tertiary strata, though their fossils are those of the white chalk, whilst the chalky character is carried downwards into the green-sand. All these modifications of lithological character must be anticipated by the Geologist, and his skill is exercised in seeing through the obscurity to which they give rise, and tracing out the boundaries of sea and land, of bay and ocean, at each successive epoch. In doing this, he will sometimes find that the mineral conditions remain unaltered from one geological epoch to another, as is certainly the case in the Mediterranean, the Scaglia or white limestone with its flints having been in part deposited during the oolitic and in part during the cretaceous periods. Sir R. Murchison has now fully established the

existence of a transition member between the chalk and tertiary formations.

Few phenomena are more striking, or have engaged more attention, and excited more speculation, than the occurrence of long lines of flints in chalk. The marked contrast between the dark hue of the flint and the pure white of the English chalk, has without doubt led in the first instance to the special attention given to chalk flints, as the occurrence of silicious nodules similarly arranged is not confined to the chalk, having been noticed in the mountain limestone and in the oolite; nor is the arrangement by nodules always the prevailing one, as in the chalk of Ireland, for instance, extensive layers or beds are very common, as they are also in the oolitic and cretaceous portions of the white limestone of the Mediterranean.

The origin of chalk flints has excited much speculation, though it is evident from the preceding observations that the question cannot be confined to the chalk alone. A microscopic examination of the chalk flints has shown that they contain numerous infusorial remains, and Ehrenberg was disposed to consider that they had been formed almost exclusively of such animals. On the other hand, the discovery of the texture of sponge in the flints has led Mr. Bowerbank and others to ascribe them in like manner exclusively to a spongeous origin; and a third party is more disposed to look upon the silica as having been held in solution by thermal waters, and when deposited in a gelatinous state to have enveloped the sponges and other bodies it contains. It is highly probable that all these actions have contributed to produce the result; and when the peculiar affinity of silica for organic substances is considered, there can be little doubt that sponges have materially contributed to the production of chalk flints, though without being considered a necessary basis for all flints. As yet, the comparison of flints and cherts in various formations has not been carried out in a perfect manner, but it may be assumed as certain that they will be

found to exhibit a material and characteristic difference in their zoological remains.

The cretaceous system is peculiarly rich in fossils, the whole mass even of the white chalk, as has been shown by Professor Ehrenberg, swarming with infusoria and other microscopic animals, in addition to the multitude of those of larger dimensions, as echinida, cephalopoda, &c. The spongiadæ and alcyonidæ are abundant: of the crinoidæ there is the peculiar genus marsupites; of the echinida, the genus ananchytes, and a profusion of species of many other genera; of the mollusca generally, the remarkable genus hippurites deserves special attention, as its true nature is still doubtful: the genus spondylus (plagiostoma and podopsis) has a very characteristic species in plagiostoma spinosum; the genus pecten affords in P. quadricostatus and P. quinquecostatus the type of a new genus, rhynchonella: the genus inoceramus abounds; whilst of the cephalopodous division there are many most characteristic genera and species, such for example as the genus turrilites, a chambered shell with an external turreted form, the beautiful genus baculites, which unites a straight form with the sinuous septa of the ammonites, the hook-shaped hamites, and a great number of ammonites and nautili, producing in this order alone an assemblage so strangely different from that of our present tropical seas, where a single nautilus alone remains, as justly to excite our admiration and surprise. In fish there is a nearer approach to the existing epoch, as the genera squalus, galeus, and lamna occur; of reptiles, there is the peculiar genus mososaurus, and in England birds here first appear. Practically, the chalk hills are well known for their smooth outline and surface, and for the short herbage of their downs, so fitted for sheep pasture, whilst the marly beds of the lower portion of the system have long been known for their fertility, as specially noted by White of Selborne. In countries where the chalk is more indurated, resembling the oolites, as in Greece, the tame character of its hills is changed to a far more bold and striking outline, resembling that of

mountains of quartz rock. The value of the chalk for its lime, being easily worked and burnt, is well known, and though soft, it can be used as a building stone. The white limestone of the Mediterranean, which is partly chalk, is an excellent building stone, though, being brittle and hard, it is dangerous in such portions of military buildings as are exposed to cannonade. The flints, made up into a species of concrete and strengthened by stone quoins, were extensively used in the walls of ancient churches, and are still so applied; they are also used as a road stone, but being extremely brittle, and breaking with sharp cutting edges, they cannot be considered well fitted for such a purpose. In the lower part of the system, the green-sand or quadersandstein becomes more practically useful on the Continent than it is in England, though the soil proceeding from it is much less fertile. In Saxony, the quadersandstein,—so called from its breaking into quadrangular portions,—is celebrated as a building stone, the colour being pure and good; and as the pläner (or gault) is there almost deficient, the upper and lower quaders are nearly in contact, and each yields its valuable bed of building stone. In other localities, as at the foot of the Schneeberges and in the Gottleube Valley, the position of the pläner is marked by a line of water springs which it throws up: westward, the pläner, which had almost thinned away, takes an unusual development, stretching up into and occupying the place of the upper quader, which is there wanting. In the valley of the Elbe, the boundary hills and the bottom of the valley itself at Meissen are of granite and syenite; and at Dresden a depth of 856 feet was bored through without arriving at the granite. If this accumulation of quadersandstein and pläner-kalk could be removed, and the basin containing it laid bare and then filled with water, an inland sea would be formed, the bottom of which would be more than 500 feet below the present sea level, and the surface of its waters about 300 feet above; but the sandstones and limestones were a marine deposit, so that after an epoch when in not very distant countries

land plants were growing, and an extensive fresh-water deposit forming, this basin must have been depressed more than 300 feet below its present level, and have then been a deep hollow in the sea; another of the surprising results, like that of the Wealden, which geological research has made known.

TERTIARY CLASS OF FORMATIONS.

At this period of geological history, the present order of creation begins to appear, as the remains of animal species which still exist are amongst the relics of the extinct. Sir C. Lyell has made this circumstance the groundwork of subdivision, and adopted terms signifying, as it were, the dawning and gradual progression of the existing light, and a subdivision depending on the proportional number of existing species, as shown in the following Table, extracted from his 'Elements;' a principle of classification, however, which is much disputed by some philosophers.

Periods.	Localities, &c.	Per centage of recent species.	Number of fossils compared.
Post Pliocene .	Fresh-water of the valley of the Thames	99 to 100	40
Newer Pliocene	Marine strata near Glasgow	85 to 90	160
Older Pliocene.	Norwich crag	60 to 70	111
Miocene	Suffolk, red and coralline crag	20 to 30	450
Eocene	London and Hampshire . . .	1 or 2	400

The two lower subdivisions of this Table are more satisfactory than the upper, being established on a comparison of large and nearly equal numbers, so that the discovery of a very considerable number of recent species would be required to affect materially the comparison; whereas in the upper the numbers are so much smaller, and so unequal, that the results would be materially disturbed by the discovery of a moderate number of recent species. It is necessary also to bear in mind, that in approaching the existing epoch, and the organic constituents of the present creation, it is only natural to

expect that evidences of similar physical conditions should be discovered; and as the fauna and flora of various parts of the present world are widely different from each other, so also must have been those of far separated localities, in periods which exhibit so much of the zoological characters of the present. In determining, therefore, the exact place of a deposit in the series of tertiary formations, the fossils should be compared with the recent species of the neighbouring coasts and seas, the fauna and flora of each local deposit becoming, as it were, independent, as the fauna and flora of many recent localities now are. On this principle, so well explained by Sir C. Lyell, the contemporaneous fossils in deposits of each tertiary epoch, and specially in the more recent, may, at various parts of the earth's surface, have scarcely any resemblance to each other, although in each locality conforming to the general rule of a growing approach to the recent types; and the tertiary formations must be considered as made up of many local formations, the exact mutual relation of which to each other it is sometimes very difficult to determine. The marine and fresh-water beds appear to have been deposited in extensive basins, and it is remarkable that the great cities of London, Paris, Mentz, and Vienna, have been founded on such ancient basins. The great brown coal formation, however, which is spread over a large portion of Germany, and abounds in land plants, does not appear connected with a basin sufficiently marked by any depression of its surface to explain so great an accumulation of vegetable matter as is seen at Zittau in Saxony. In general, the tertiary deposits of England do not attain any great terrestrial height, no elevating force having been exerted beyond what was necessary to raise them partially above the sea level; but along the axis of greatest movement, both in Europe and America, the case is different, the Nagelflue of Switzerland, with its brown coal and limestone, skirting the Alps in a chain of mountains 6000 feet high, the thickness of the deposits being 2000 feet. These deposits are very widely spread, occurring

in North and South France, in the South of England, as also, in its upper members, in Scotland and Ireland, in North Germany, and along the Rhine in Middle and South Germany, on both slopes of the Alps and Apennines, in Sicily, on the coast of Africa, and specially on the shores of the Mediterranean, in Poland, in North and South Russia, in North and South Asia, as, for example, in the Bay of Bengal, in the East of North America, and in Equatorial America, &c.; so that in almost every part of the globe traces have been found of that gradual approximation to the present physical and zoological conditions of the earth's surface which is learnt from the study of tertiary deposits. In a few Northern localities, it is supposed that a tendency towards a colder climate can be traced within the later tertiary epoch; but generally the climate appears to have continued nearly tropical.

EOCENE AND MIOCENE.

The English tertiary deposits are very local, and only important in the lower members. The basins of London and Hampshire are the lowest geologically, and belong to the eocene period. They are bounded and underlaid by the chalk, and their strata consist of sands, clays, and gravels. On the variation of mineral character, a subdivision has been founded into the upper sand or Bagshot sand, the London clay, and the plastic clay, which consists of alternating beds of clay, sand, and shingle; but as such peculiarities are purely local, and are not accompanied by any important zoological differences, they cannot be adopted as a sufficient basis for geological classification, though within these districts of great practical use, as will be seen in treating of the subject of 'Springs.' There are several shells, such as nautili, &c., of a tropical type, and many plants also, more than seven hundred of which have been discriminated; and again in the reptiles, the teeth and bones of many crocodiles and turtles, and even the bones of a large serpent, have been found. The remains of a bird, of various quadrupeds, and of a monkey of the

genus macacus, all concur in this testimony to a warm climate. Though corresponding in epoch, as shown by its organic remains, to the London basin, the deposits of the Paris basin are singularly different, being composed of a coarse white limestone, calcaire grossier, a silicious limestone with beds of crystalline gypsum and of flint, and marls with some clay and lignite. The celebrated Montmartre gypsum quarries were the classic ground of the great Cuvier's wonderful researches and discoveries. The great mineral difference in these deposits in the two basins leads to similar differences of practical application. The London clay beds sometimes abound in calcareous nodules, used for making Roman cement, which often contain marine shells, and sometimes the remains of turtles and fruits. When traversed by cracks and veins dividing the mass into parts, as by septa, they are called septaria. Harwich and the Isle of Sheppy are well-known localities of these nodules. In the Paris basin, the calcaire grossier furnishes, in some of its varieties, very good building stone, and the silicious fresh-water deposit yields an excellent millstone. Mr. Prestwich has made an important alteration by proving the true London clay, including the Bognor clay, to be more ancient than the calcaire grossier, and therefore to correspond with the sands, &c., of the Paris basin: he discovers, however, in part of the Hampshire series the true equivalent of the calcaire grossier. The range of the London clay has been extended through a large portion of the N.E. of Europe, by Dr. Girard, of Berlin.

The miocene epoch is represented in England by the Suffolk crag, which is subdivided into the coralline crag below and the red crag above. The coralline crag is very local, and is generally calcareous and marly, being a mass of shells and small corals, whilst the red crag is a highly ferruginous grit. Although the thickness of both members of this deposit is very small, not together exceeding 60 or 70 feet, the number of fossils is very great. Mr. Searles Wood has obtained 230 species of shells from the red crag, and 345 from the coralline,

150 of which were common to both. There is a considerable difference in the proportion of recent shells in the two divisions; and as the lower had been disturbed before the deposition of the upper, they exhibit a striking modification consequent on the change from a coral reef to a shingle bottom,—an example of existing coral reefs, which may be applied to show that they are not necessarily of great thickness, the product of almost infinite ages, or that they rest on the peaks of submarine volcanoes; since now, as in the ancient epochs, a growth of coral may have commenced on a sand or mud bank, have been interrupted by a new deposit of a similar kind, and then again renewed, such alternations being frequently observable in the carboniferous period.

Practically, the formation varies in importance in different districts. In Suffolk, the coralline crag yields a soft building stone, and the marls are useful as manure. In the Styrian Alps, limestones of a coralline and of an oolitic structure are largely developed, and the molasse, from the ease with which it is cut, is also valuable.

PLIOCENE FORMATIONS.

It is unnecessary to dwell long on the upper or newer pliocene formations, as they are very feebly represented in the British Islands, being confined to minor deposits of sand, gravel, and clay. On the Continent, however, they are very largely developed, extending in Sicily over nearly half the island, and attaining an elevation of 3000 feet, being composed partly of calcareous and partly of argillaceous strata, and exhibiting by the occurrence of recent species of shells amidst such a mass of stratified matter, a striking proof of the accuracy of geological reasoning as regards the older formations. The older pliocene in England is supposed to embrace the Norwich crag, which was formerly confounded with the coralline and red crag of Suffolk. In Italy, the Sub-Apennines afford a striking exemplification of the great development of these comparatively recent strata, and the blue clay of the Mediterranean, rising

sometimes to the height of 1000 feet above the sea, is also of this epoch. The thickness of the Norwich crag, consisting of sand and loam, and considered an estuary deposit, is small, about 40 feet, and the newer pliocene is also insignificant in vertical extension. In Sicily, the newer pliocene, though so vast, is still marine in character, but in Russia the singular phenomenon is again observable of an equal extension of fresh-water deposits, a vast mass of argillaceous limestone occurring around the Caspian, which Sir R. Murchison calls the Aralo-Caspian, or Steppe limestone, and of which the univalve shells are of fresh-water origin, being associated with bivalves, which are common to partially saline or brackish water, but without corals. The thickness of this supposed member of the pliocene is in some places between 200 and 300 feet, and it attains elevations of 700 feet above the present level of the Caspian. It is remarkable that whilst the species of testacea of the newer pliocene formation were nearly identical with those of the existing period, there should still have been so marked a distinction in the animals of a higher class, as is proved by the bones of the various celebrated bone caves and ossiferous breccias of all parts of the globe, a difference which continued even beyond the limits of the pliocene. It is also remarkable, that whilst in the old world the general type of such organisms is conformable to that still existing, though indicating the extension of higher animals now confined to warm climates far northward of their present limits, there is in Australia a type peculiar to itself, which extends back to this period, and even to the oolite, so that this vast region was already isolated from the rest of the world.

The connection of the ancient lava currents of Auvergne with the tertiary strata has already been noticed, but it requires a few additional remarks. The age of the stratified deposits of the country is considered by Sir C. Lyell to be generally eocene, although some portions may possibly extend upwards to the miocene, whilst the base of the system being granite, was therefore either eruptive or metamorphic of a more ancient

date. Sir C. Lyell describes successive gravel beds, the alluvions of different ages, covered by lavas; and his still later inquiries have shown that in the Valley of the Couze at Nechers, the lava current of the Puy de Tartaret has passed over a red sandy clay, rich in the bones of mammals, which are associated with those of reptiles and of birds, and with several *recent* land shells. The bones, though closely allied to those of recent species, are considered distinct, and include the equus fossilis of Owen. Sir C. Lyell, from the superposition of the lava, is enabled to affirm that the bone beds, in whatever way the animals were destroyed and their relics so imbedded, belonged to the alluvial formations of the river bed and river plain at the time of the flowing of the lava of Tartaret; whilst he shows, from the existence of an ancient Roman bridge, not more recent though probably much older than the fifth century, which spans with two arches the river Couze, abutting on both banks against the lava which had thus been cut through and formed into the present existing ravine fourteen centuries ago, that as respects the events of human history, the lava of the Puy de Tartaret was at least of great antiquity, and referrible either to the close of the newer pliocene or to the post-pliocence period, a period when "the mollusca were identical with those now living, although a great many of the mammalia belonged to species now extinct." This recurrence of alluvions and even of ossiferous beds, with overlying streams of lava, deserves especial attention, as it is utterly impossible to reconcile such repeated volcanic eruptions to any one catastrophe. In countries where the tertiary strata are fully developed either as deep sea or as great lacustrine deposits, they supply valuable building materials both in limestone and in sandstone; the celebrated Carrara marble, once considered primitive, belonging to the tertiary epoch. The fossil bitumen so extensively used in asphalte pavements, namely, that of Bastenue, a small village of the South of France, 15 miles north of Orthez, is tertiary. The basis of the formation in which the bitumen is found is a sandy lime-

stone, which has been allocated to the cretaceous system. The overlying beds are variously coloured sands and clays, which are 50 or 60 feet deep, and covered by gravel and sand, which extend many miles in every direction. The beds are usually horizontal, though sometimes much disturbed by the intrusion of igneous rocks. Under about 45 feet of variegated sands and clays there is a small quantity of bitumen in a bed of blackish sand, 4 feet thick: from 5 to 15 feet of bitumen are then observed, the upper part of which is mixed with loose and coarse sand, the lower being more compact, and mixed with finer sand. In some places there are 10 to 15 feet of sand without bitumen, whilst in others the bituminous sand is thicker, and rests directly on the secondary sandy limestone. In two localities, marine shells have been found in the bituminous sand, and Mr. Pratt refers them to the miocene period. The shells are arranged in layers, and are quite perfect, the valves not being separated from each other; and the bitumen, when in a soft or liquid state, was, in Mr. Pratt's opinion, forced into the shells, after their deposition in the sands in which the animals lived, filling even their smallest cavities. The eruption of the bitumen is supposed to have been connected with the appearance of the ophite, an igneous rock which has produced such great changes in the Pyrenees. The bitumen is easily cut when first exposed, but in a few days it hardens so much as to become incapable of purification: the purification is effected by boiling the sandy mixture in a large quantity of water two or three times, when, by continued and careful stirring, the sand gradually settles to the bottom, while the pure bitumen rises to the surface and is taken off. A small portion of bitumen occurs in the tertiary rocks of Anti-Paxo, and again in a larger quantity at Zante.

The existence of gypsum and salt in the tertiary strata has been already noticed.

QUATERNARY OR POST-PLIOCENE.

Our inquiry has now come to that point, where, though we still see in the recent results of geological phenomena evidence of the formative processes of nature,—coral reefs still rising from the depths of the Pacific,—conglomerates being still formed in the Mediterranean,—beds of marl being still deposited in lakes,—travertin being deposited from mineral springs,—and peat being observed to have formed over fresh-water shells, the bones of land animals, and even the works of human art,—we are still kept at a distance from the recent epoch; for although the shells are all of recent species, they are generally arranged in positions and associated with detritic matter of such a description that their appearance indicates the action of forces prior to the present order of things. These masses, the true post-pliocene, though now exposed to view and frequently found at high elevations and of great depth, have evidently been, like the antecedent formations, under the level of the waters either of lakes or of seas, whilst true recent strata are, in most cases, still in the position from which the former have emerged. The beds of sand and gravel spread over so large a portion of the earth have always attracted attention, and for a long time were considered the results of a passage of diluvial waters over its surface; but a rigid examination of the peculiar characters of these deposits has shown that such an opinion is untenable: for example, they sometimes consist of deep beds of sand, separated by fine clay partings into a multitude of beds; sometimes they are composed of alternating layers of sand and gravel, which exhibit cross lamination; sometimes they consist of clay with imbedded boulders of various rocks and of various sizes, the term boulder being properly applied to rolled or rounded masses; sometimes they contain marine shells, sometimes bones, and sometimes they extend over large spaces and occur at great altitudes and of great thickness, without any trace of organic bodies. Many marls and clays or silt, with land and fresh-water shells, belong to this division. When the various circum-

stances attending such deposits are considered, it is evident that they cannot be ascribed to any one great wave, or to the action of tumultuous waters, continued only through a very limited time. The substances forming these deposits have been broken up, triturated, and moved by water, and the term drift therefore has been applied to many of them ; but though all such matter and substances have been more or less drifted, their distribution must have been modified by many local peculiarities, giving rise to deep deposits of sand in one place, and to long continuous banks or shoals in others. The sounding lead testifies that such modifications of recent drift are now taking place; and it is reasonable therefore to expect them in ancient drift. One great progressive step has been only recently taken, by separating the great 'erratics,' or those large angular masses of rock which often rest on the surface of sand or gravel, from the beds on which they lie, and thus distinguishing them from the rounded boulders either connected with the latter, or heaped up with clay as deep accumulations in hollows. These erratics are now generally believed to have been transported by ice, just as fragments of rock are now drifted along on icebergs.

In Northern Sweden the phenomenon of drift is strikingly exhibited in long trâinées, whilst the rocks are worn down in undulating surfaces, and examples are exhibited of rounded northern and abrupt southern sides. It is impossible to enter into details, and it may be therefore generally remarked, that the superficial detritus, so long called diluvium, exhibits itself in several distinctive phases. 1. As deep beds of sand, not heaped up in one mass, but manifestly deposited in successive layers, and therefore, though doubtless triturated by the action of water, and even moved along by currents, comparatively tranquil and regular deposits. 2. As lines of gravel and of gravelly clay, with rounded boulders which sometimes surmount the more quiet deposits, and by their definite direction in such traînées for even hundreds of miles, indicate the action of powerful currents, moving in Northern Europe, in a slightly

divergent direction from the Scandinavian Mountains to the south on one hand, and from the south to the north on the other; the latter remarkable fact, a result of Sir R. Murchison's recent inquiries, indicating that the transport was not effected simply by the usual submarine currents flowing from north to south, but partly, at least, by undulations of the bottom, which caused powerful waves of translation in all directions from the axis of disturbance. 3. As 'erratics,' or large angular blocks, which are not immersed in the sand, mud, or gravel, but rest on its surface, or on ridges of rock where there is no such superficial covering; and it has been impossible hitherto to adduce any sufficiently satisfactory cause of the translation of such masses, which, having preserved their angles, cannot have been exposed to the rolling action of water, other than that of moving ice. 4. In the preceding cases, the detritus is supposed to have been foreign, or to have travelled; but it is very often partly local, and then indicates the wear of the adjacent rocks, both by the direct action of the sea against them, and by its power of attrition in moving fragments along a coast or a bank. Where both forms of detritus occur, great care is required to discriminate between them, and determine which of the two is the underlying or overlying. 5. Connected with this question is the phenomenon of raised beaches, although it must not be supposed that each deposit so called has actually been a beach, in the ordinary sense of that term. Mr. Smith, in tracing the successive upheavals which have given to the rock of Gibraltar its present form, notices several modern detritic beds which contain recent marine shells, and occur at various heights up to 700 feet above the present sea level. Some of these beds are connected with ancient sea-worn caves, and would be therefore justly classed with the effects of a sea beating against a beach and cliff; but if the phenomenon be observed more extensively, it will appear at least possible that some such deposits are merely forms of current drift, and were not, strictly speaking, beaches. Sir R. Murchison supposes the ancient limestone of Gothland to have

been eroded, whilst yet beneath the sea, by ordinary marine action; but this description of action must as yet be considered only conjectural. He then supposes the limestone exposed to powerful denudation by the passage over it of heaps of fragments of crystalline rocks drifted from the north, and impelled forward by powerful waves of translation, according to the theory of Mr. Scott Russell and Mr. Hopkins, by the wearing action of which the exposed northern face and the summit were, it is supposed, broken, polished, grooved, and striated, whilst the drifted boulders were shot over the southern escarpment, and lodged at its foot, there forming a bank of gravel, without wearing away the lee or protected side of the still submarine hillock. The waves of translation having subsided, a glacial or ice-floating epoch supervened, during which ice-bergs and ice-flows transported large angular blocks, and deposited them sometimes on the surface of the denuded limestone, and sometimes on the water-worn gravel or Osar, and at length, the island having been uplifted above the level of the sea, it would exhibit traces of these past actions in its worn northern face, in its summit cap of gravel surmounted by angular 'erratics,' and in the gravel bank at its southern base, which would *then become* a beach. New elevations would raise the island still higher, and now, by the action of the waves against its surface, *local* gravel would be formed of the fragments of limestone and be fashioned into a recent beach.

Similar phenomena have been observed in America; and whilst in Europe the boulder formation has been traced southward to the 52° of latitude, in America it has been observed to extend to the 38½°, to be occasionally more than 200 feet thick, and to bear on its surface 'erratics,' one of which, a block of greenstone 100 feet in circumference, was noticed by Sir C. Lyell on the summit of a high hill of sandstone, the largest European erratic on the Island Fohnen measuring 44 feet across. The surface of rocks, when laid bare, are observed there, as in Europe, to be striated, furrowed,

or smoothed. These phenomena, extending from the northern elevated districts towards the south, required a general force, such as that which now effects the transmission of the Polar waters to the Equator, and cannot be explained by the waves of pulsation consequent on elevating forces alone. Further, as the 'erratics' pursue a similar direction with the long traînées of gravel, the currents preserved a general direction for a long period of time, as is now the case with icebergs. To the north of the Scandinavian chain, the 'erratics' have moved to the northward; but their extension in that direction has possibly not been traced sufficiently far to remove them from the possible action of glaciers, as it is reasonable to assume that the glacier must have co-existed with the floating sheet and berg of ice, and co-operated with them and with marine and lake currents in transporting the fragments of rocks by land and sea. Elevatory forces may have produced waves of translation during the same epoch, and given rise to the formation of radiating lines of gravel, and by the modification of the usual action of currents, have at the same time led to the deposition of 'erratics' upon them; or, in short, all the causes which in the present state of the earth are known to co-operate in producing changes and results which will become the matter of inquiry to future intelligent beings, co-operated in the period now under discussion to produce those which were once classed under the general term diluvial, and are now called quaternary, post-tertiary, or glacial from the numerous manifestations of the action of ice over large spaces exhibited in the wearing or striation of rocks, even in some cases on their under or overhanging surface, in the transport of erratics, and in the apparently sudden destruction of many large animals now peculiar to warm climates, which are found either in the gravel itself or in caves partially closed by it, or frozen up in the ice.

RECENT OR ALLUVIAL.

The natural phenomena which can be now studied are valuable guides in estimating those of past epochs; and by many analogies of alluvial deposits may be learnt the mode in which more ancient deposits have been formed. The action of rivers may be estimated by the extension of the deltas at their mouths, and that of the sea observed in all its phases. The processes of destruction and of formation connected with these actions extend over the whole earth, though, being necessarily modified by many local peculiarities, they produce parallel not identical formations, the contemporaneity of which it will be difficult at more remote ages to determine. These formations may be divided into mechanical, chemical, and organic, and also into land and sea formations, volcanic products being connected with each.

Mechanical Deposits.—Torrents and rivers, in their course through mountain regions, carry along with them a mixture of large and small fragments torn from the boundary rocks, and deposit their load in the lower and more tranquil portion of their course, as gravel, sand, or mud,—the nature of the deposit and the distance to which it is carried being proportioned to the strength of the current; and this simple and constantly occurring natural event exemplifies the removal of portions of rocks from their native bed and their subsequent deposition, and the formation of alternating beds of clay, sand, and gravel. When a river passes through rocks rich in ores or in precious stones, its waters often separate from their matrix those substances which from their superior weight remain behind, whilst the finer matter is hurried onwards. Deposits of this kind are valuable from the quantity of ore and of gems which they sometimes contain, and which are separated by repeating the natural process, or again washing away the remaining fine matter. Particles of gold, platinum, iridium, rhodium, palladium, osmium, chrome, and magnetic iron, are obtained in the Ural chain of Russia and in Brazil, and of

gold in Wicklow and elsewhere; the term stream gold or stream tin, &c., being applied to such products. As yet, platinum has only been obtained in this secondary manner, and the greater proportion of gold is similarly procured, as well as a considerable part of the tin, as also the zircon of Bohemia, the chrysoberyls and hyacinths of Ceylon, the diamonds of Brazil and of the East Indies. In Borneo, gold has been found mixed with alluvial matter in limestone caves. The gravel of the Rhine is estimated by M. D'Aubrée to contain an amount of gold equivalent in value to 165,828,000 francs, or £6,564,025.

Mechanical Deposits.

Deltas.—Where rivers discharge their suspended mud into the sea, and where the coast is shelving, and there is no powerful marine current, a delta is often formed by the deposition of mud at the point where the waters have lost their transporting power. It usually commences at the centre of the river's mouth, an island being first formed, which goes on extending and widening till a triangular space is occupied by the deposit, the apex being directed upwards, and the base facing the sea; and this form having been first noticed in the mouth of the Nile, the name Delta was applied to it from the Greek letter of that name. Sometimes, as in the Nile and the Rhine, several islands are simultaneously formed, so that the delta is finally a compound one, and is separated by various channels. The delta of the Ganges is still more remarkable than those of the Nile and Rhine, its perpendicular depth from the apex to the base being about 180 miles, and therefore exhibiting a formation comparable in extent to many of those of past geological epochs.

From the action of the Sea.—The sea effects a change in the form and position of the land with which it is in contact; for whilst at one point its waters encroach upon and carry away the land, at another they deposit new matter, and increase it; and as they contain from three to four per cent. of various mineral salts

(as chloride of sodium, chloride of magnesium, sulphate and carbonate of magnesia, sulphate and carbonate of lime), the formations produced are often more fixed and solid than those of fresh water. This is specially the case in warm climates; and as the fragments of shells as well as comminuted portions of calcareous rocks are often mixed with the deposits, sandstones are sometimes formed, sometimes limestones, sometimes conglomerates. In a formation of this kind at the Island Grande Terre, near Guadaloupe, human remains have been imbedded, and many such are in progress of deposition below the waters of the sea, and will be brought to light by such upheavals of the coast and sea bottom as that which so strikingly affected the coast of Chili.

Chemical Deposits.

Calc Tuff and Calc Sinter, or Travertin.—Mineral waters come to the surface, and as they pursue their course along it, by the influence of light, air, evaporation, loss of temperature, absorption, and escape of carbonic acid, deposit mineral matter. Springs charged with lime yield in this manner calc tuff, or sinter, which, in cold springs, assumes the form of calc spar, and in hot springs that of arragonite. Calc tuff is usually a porous mass, but sometimes its layers are sufficiently firm to be used in building, and are then valuable from their lightness. The most remarkable example of such 'travertin' formations is to be found in Italy, and so rapid is the progress of deposition, that at the Baths of San Filippo, a mass, 30 feet thick, has been formed in twenty years. These springs are made use of to procure stone casts, the lime being deposited in a firm and solid state on models immersed in the water.

Silicious Tuff, or Sinter.—Thermal springs deposit, on cooling, much silex. The hot springs of Iceland, and especially the Geyser, are of this description. At intervals of a few minutes, a lofty column of hot water is thrown up, and then a dense fog overspreads the surrounding ground, and from this condensed spray the silex is deposited in the porous form of

tuff, or sinter, whilst, in the interior of the basin, a species of opal is formed. Several springs which deposit silex are found in the Azores; and it is very probable that semi-opal and hyalite, which are frequently found in the crevices of basalt, and in short, most of the silicious minerals which are so abundant and so beautiful in that rock, have been formed in a similar manner by the filtration or absorption of the water by which the mineral matter had been originally dissolved.

Bog Iron (*Limonite*).—Ferruginous springs or waters deposit a brownish red scum of peroxide of iron on their banks, or at the bottom of bogs and marshes, masses of iron ore, which has been called from such localities bog or marsh iron; and as sand or gravel may be mixed up with and consolidated by the mineral matter, a variety of ironstone is formed, which has been called sand ore. In Sweden, bog ironstone has been fished up from under the sea, where, according to Hausmann, it is still produced, and it would be interesting to compare the microscopic structure of this ore with that of fresh water. The presence of phosphoric acid in bog iron ore, so unfavourable for smelting, is probably due to the decay of organic bodies in the water during its formation.

Deposition of Saline Bodies.—The saline deposits thrown down by springs, streams, and lakes are not extensive. From the mineral springs of the Baths at Vienna, a fine powder is precipitated, which consists of gypsum and muriate of lime. In the South of Russia, several lakes annually overflow their banks and deposit a saline crust; a phenomenon which is much more common in the lakes, and in the very low grounds, of the warmer zones. In Egypt, soda has in this manner been deposited in large quantity. The extensive turf moors at Franzensbad, near Eger, are partly coated with a white saline crust of sulphate of soda (Glauber salt) and sulphate of iron. Some salts exude out of rocks, as is the case with saltpetre (nitrate of potash or nitre), in the limestone caverns of Brazil and of Ceylon.

Mineral Oil, or Pitch.—In several parts of the earth there are springs of a mineral oil, which on drying becomes either

asphalte or a species of coaly mass. The Carpathians and the vicinity of the Dead Sea are rich in these springs, which in the island of Trinidad form almost a sea of asphalte.

Organic Formations.

From the action of Plants or Animals—Turf.—This formation is in some instances covered by more modern mineral deposits of little extent, and in others exhibits a passage into the brown coal, which is a constituent part of the earth's crust. Turf consists principally of an accumulation of marsh and water plants, especially of various species of moss, the lower layers of which have in succession died, and through the action of humic acid been changed into a peculiar brown, felted, slimy, and combustible mass. In some layers of turf, the remains of plants are so decayed and changed that their original condition can only be inferred, but in others the actual species of the moss can yet be determined. In some bogs, the growth appears to have ceased, whilst in others vegetation is still vigorous on the upper surface. In Alt-Warmbrücher moor, near Hanover, which is being cut for the second time, the turf has been re-formed, according to Leonhard, in fifty years, and during the last thirty years a layer from 4 feet to 6 feet thick has been in course of formation. At Franzensbad, near Eger, a similar fact has been observed, the exhausted turf hollows having been again filled with new turf plants in from ten to twenty years, which are formed into useful turf in from fifty to one hundred years. The great bogs of Ireland are amongst the finest examples of this kind of formation, both as regards their extent and depth; and although no very detailed or satisfactory observations have been made on the new growth of bog in old exhausted hollows, where drainage and cultivation have not so modified the conditions as to stop it, very slight observation is sufficient to show that the first step of the accumulation of moss plants can yet be traced. Keferstein has remarked that turf formations are rare on calcareous and frequent on silicious bottoms, but Ireland is against

the generality of this observation, as turf is abundant in some of the limestone districts, and has in several cases grown over lacustrine deposits of shell-marl. Thick beds of turf occur on the summits of some high hills in Ireland and other countries, where a clay bottom retains the moisture. On the banks of the North Sea, a species of turf is formed from accumulations of sea weed. Large masses of bog have sometimes been detached, and become floating islands, one of which, on the Gördauer lake, in Prussia, was so large as to support a hundred head of cattle, until, in 1707, it was broken into three parts by a severe storm. Sometimes turf is found below the high-water level of the sea, as at Greifswalde and Geageland, on the East Sea, and on the north coast of Ireland, near Portrush, where the elytra of beetles (fresh and bright) occur between the layers of turf. Turf is also formed in the warm zones, as at San Paulo in the Brazils. In the Irish bogs, the roots, trunks, and fragments of the branches of large trees, both oak and fir, are abundant, and, in several instances, two or three successive sets of the roots stand upright one above the other. As before observed, turf exhibits a connecting link between the existing epoch and the next preceding it. It is sometimes very compact, and full of iron pyrites, which frequently induces spontaneous combustion and the formation of sulphates, often contains fresh water shells, and is covered by layers of sand and clay, and as it passes into brown coal is more nearly connected with the diluvial than the alluvial section of the post-tertiaries. In Langensalza, a bed of such turf with stems of trees was found under a covering of 12 feet of sand and 7 feet of earth. At Wittgendorf also, near Sprottau, in Silesia, turf rests on fresh-water marl, and is covered with sand and gravel. A wooden bridge, made by Germanicus in his German war, was found under a bog; and in Galway, a hut and paved passage were found under 30 feet of bog by the late Capt. Wm. Mudge, R.N., both being interesting examples of the manner in which such formations, when unrestrained by cultivation, spread over and deform the surface of the earth.

Submarine Forests.—On various parts of the coast of Great Britain and of the North of France are found the remains of ancient growths of trees and plants in positions below the level of the sea, though of species still living. They are sometimes exposed by the encroachment of the sea on the coast, and at other times simply by the ebb of the tide, and probably owe their present position to a partial depression of the land. On the western coasts of Jersey, Colonel Lewis has noted a fine example of such forests.

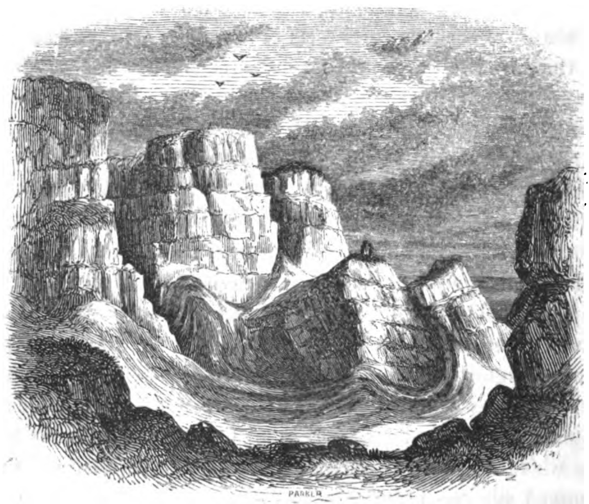
Coral Reefs and Islands.—They prevail in the Pacific and Indian Oceans and in the Red and Mediterranean Seas. Recent researches, especially those of Quoy, Gaimard, and Ehrenberg, have shown that the growth of coral does not continue in great depths, and that coral reefs or islands are only incrustations on the inequalities of the sea bottom, whether due to mountain masses not yet elevated to view, or to banks of detritic matter, and are therefore not generally more than 20 feet or 30 feet thick. Whilst, then, such formations explain the nature of the true coral reefs of ancient epochs, and account for the deposits of shale with calcareous layers of corals so common in the carboniferous system, they cannot alone explain the formation of the greater masses of limestone, though polypes may have even contributed to it.

Infusoria.—Whole masses of rock consist of little else than infusorial remains, as tripoli, polishing slate, &c. Sometimes the infusoria which have formed these strata belong to extinct and sometimes to still living species, so that the microscope, guided by an Ehrenberg, carries on that reasoning on successive creations which had been founded on the contemplation of higher organisms. The silicious skeletons of these minute beings are accumulated at the bottoms of marshes and stagnant waters, as in the turf moor near Eger, and thick beds of a white silicious powder have been formed, consisting of the unmixed silicious portions of still existing infusoria. Some of these infusorial substances, such as tripoli, polishing slate, &c., have been classed with metals, from their general appearance,

but their true character has now been revealed by the microscope. Most infusorial deposits probably belong to antecedent epochs, but that of Eger is evidently recent, and in all countries where waters flow over much decomposing silicious rock infusorial formations are to be expected.

As land-slips are phenomena of the recent epoch, they may be here noticed. Wherever a soft stratum is liable to be removed by the action of percolating water, slips in the harder superjacent rock are common, as in the Isle of Wight, &c. They are finely exhibited in Ireland, where a basaltic cap covers the cretaceous and subjacent strata. The soft liasic and oolitic beds are removed or squeezed out, and the top cracks and slides down, as in fig. 18, which is a portion of the basaltic escarpment of the North of Ireland.

Fig. 18.



CHAPTER VII.

Theory of Springs.

As water is the most important substance in nature, being the solvent by which nutrition is conveyed both to the plant and to the animal, as well as the chief agent by which the mineral kingdom has been again and again abraded or restored, it is desirable to consider that constant change and movement by which its purity and fitness for performing its several functions are insured. The ocean is the great recipient of the larger proportion of rivers and streams which flow over the earth's surface, and its waters are in constant motion, the warm currents proceeding from the Equator to the Pole, and the cold from the Pole to the Equator; whilst evaporation causes a perpetual movement of vapour upwards, which, being condensed, falls in rain upon the earth, and again returns to the sea. These simple processes bring within the reach of organic action a constant supply of this vital fluid in a pure and efficient condition, as springs, rivers, or lakes. The useful distribution of water is promoted by the physical inequalities of the earth; for had its surface been uniformly level, the falling rain would have soaked and saturated the upper strata so as to produce a swampy condition, not probably very dissimilar to that it actually possessed, over large tracts, in the earlier geological epochs. The conjoint actions of elevating and denuding forces have, on the contrary, produced chains of mountains, valleys, basins, and all the minor modifications of these three great forms. In the vicinity of mountains, the effect of this arrangement is readily observed in the river which one day struggles with its riband-like stream through a

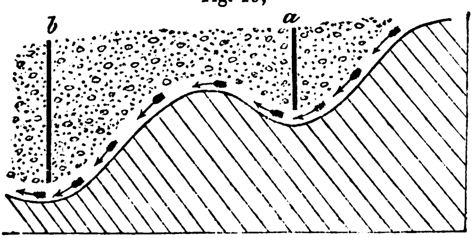
wide bed of stones and gravel, and the next rushes forward an overflowing and turbulent stream, being swollen by the sudden rains which, having fallen within the area of its leading or connected valleys, had been thereby collected into one great liquid mass. The more numerous the feeders, and the more closely connected with mountain masses on the summits of which a very large portion of moisture is always deposited over a comparatively small space, the more sudden will be the rises of the discharging or recipient river. A large portion of water is thus carried off directly by running over the surface, but another large portion percolates through the surface to a greater or less depth, in proportion to its porosity. In clayey soils, this passage of the water is very slow, and the surface therefore in wet weather becomes moist and clammy, and in dry forms a crust fissured by cracks. In sandy or gravelly soils, the passage is very quick, and the surface keeps comparatively dry; but if the soil be not very deep, and part of the water be retained by a more retentive substratum, the readiness with which the moisture is restored by a continued evaporation prevents an injurious aridity, and in consequence this condition of the surface is more generally favourable for vegetation than an impervious soil. If the sand or gravel be on the contrary very deep, and rests on an inclined surface, it acts as a filter, and whilst the water is entirely and rapidly removed, a general aridity of surface is produced. These considerations naturally lead to a theory of Springs, which will now be illustrated in detail.

1. It has been seen, that whilst part of the rain falls on the surface and runs off as on an inclined plane, another part filters through it, and when collected together in any cavity of the less pervious substratum, forms a reservoir of water. Even on the sides of mountains, especially in damp climates, this process is constantly exhibited; and whilst the general surface becomes wet and boggy, numerous springs are seen wherever an inequality has led to an accumulation of water, which issuing as scarcely perceptible rills, go on gradually

increasing as they join with others, and finally emerge in the greater valley as considerable streams. Such is the most simple and ordinary form of springs, from which, taking into consideration the peculiar modification in each case of the earth's surface, may be derived every other; and springs will therefore be superficial, small, numerous, but very temporary, where the pervious stratum is very shallow, and the inequalities of the substratum slight.

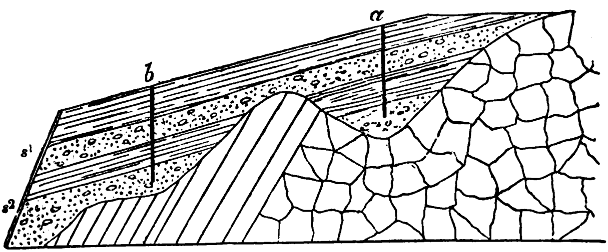
2. In addition to the water which forms the superficial springs on a mountain side, a portion may pass between the underlying rock and the superficial matter above it, whether the latter be a stratified deposit or ordinary detritus resulting from the simple decomposition of the rock itself; or should the overlying deposit be moderately porous, some of the water may pass directly through it to the underlying rock, and in either of these cases reservoirs of water will be formed in any great depression of that rock. This is a case which occurs even in granitic and highly metamorphic rocks; and as in the former, open fissures are rare, whilst superficial disintegration, especially in hot countries, has proceeded to a great extent, it affords almost the only chance of meeting with deep-seated springs. Major Baddely, R. E., has shown its application to Ceylon, and explained the principles which there regulate the appearance of springs. The underlying rock is a highly metamorphic hornblendic or syenitic gneiss, the outcropping edges of which have undergone much original modification, and is therefore supposed to form an undulated surface—thus, in fig. 19,

Fig. 19,



the hollows being filled up by a detritus, proceeding, according to Major Baddely, from the simple disintegration in situ of the more felspathic surface. From the mere inspection of the figure, it is evident that whatever may be the origin of the matter filling up the inequalities of the underlying rock, the water, either in part percolating through it, or passing between it and the surface of the sound rock, must accumulate in the hollows, and that in consequence it may be necessary to sink at *b* to 80 feet for water, although at *a* it had been found at 40; and further, that should the rock under *b* slope gradually off, and become exposed in a valley or on the side of a hill, the water may all be carried off as quickly as supplied, and produce therefore no permanent spring,—circumstances which render the search for water in such cases very precarious. It may be further added in respect to this example, that a rising or projecting spring can only be expected where the water passing between the detritus and the rock is pent up by them, and thus affords a head of water; as if it merely filters through, the pressure can only raise the spring to the height at which the water stands at the time in the reservoir or hollow. The other form of this case is, where the hollows of the crystalline rock are filled by stratified deposits (No. 20) of shale and

Fig. 20.



sand. Here, as the shale has been worn away, and the rock denuded at the summit, the water may gain access to the layer of sand (s^1), and produce therefore a spring under the bore-hole (*a*), the water being held back by the projection of

the rock to the left of it. Where the water has saturated the whole of this stratum, it will rise over the projecting rock; but as the stratum is open to the valley below, it will be rapidly discharged, and produce no permanent spring under the bore-hole (*b*). Again, under both *a* and *b*, there will be a second supply of water due to the sand stratum (s^2); but as these lower reservoirs, from their imperfect connection with the surface must require a considerable time to fill, their practical value will be in proportion to their actual magnitude, or to the quantity of water previously stored by nature in them.

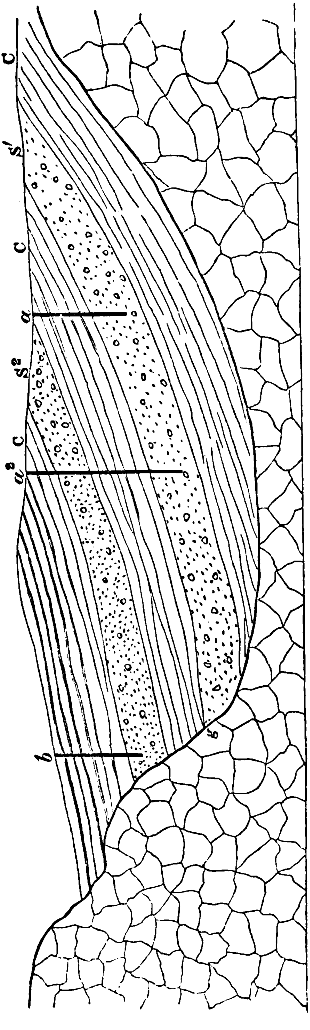


Fig. 21.

3. In the preceding instances, the accumulation of water has been considered to arise principally from that which flows over the underlying solid rock, but it may be also entirely due to that which enters directly from the stratified deposits, and is merely held back or dammed up by that rock, as in No. 21.

Here it is evident that the supply of water will be in proportion to the extent of surface on which the rain

falls, and from which it is directed to the layers of sand (s^1 and s^2), the remaining mass being either clay or some other impervious stratum. If the supply be abundant, the stratum will be kept saturated up to the line of the bore-hole (a), and a constant spring be obtained; but if it be only small and casual, there may be a spring during the rainy season, or whilst the water is making its way through the stratum, but none at a later period, and the chance of permanency will be increased as the bore-hole is carried nearer to the rocky dam at g; and the same reasoning will apply to the upper stratum of sand (s^2), and its bore-hole (b): and it may be observed also, that a bore-hole (a^2), which could only find a temporary spring in s^2, by being carried through the intervening clays, might obtain a permanent one in s^1.

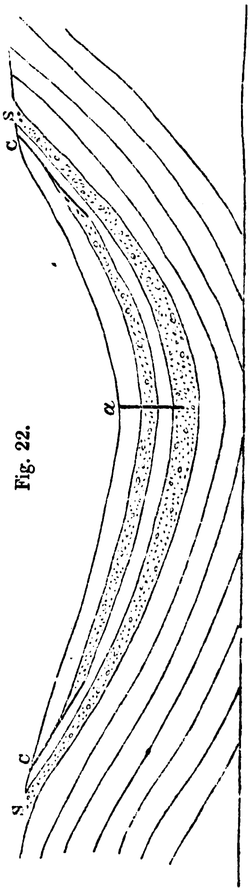


Fig. 22.

This case leads to those where the water is received and thrown up entirely by stratified deposits arranged in the form of basins or troughs; and this may happen either where the basin is produced by an undulation or depression of the underlying strata, or where it occupies the valley produced by the disruption of these strata by elevation; and as some precaution is necessary in reference to this distinction, each case will be considered separately.

No. 22 is the first case where the strata of sand and clay have been deposited in a basin of undulation, and the water entering the sand stratum (s) is prevented from

descending by the impervious strata below, and from ascending by the clay above; so that it is pent up in the sand and stratum itself. An inspection of the figure is sufficient to show that the nearer the bore-hole is made to the lower point of the valley, the more abundant and secure will be the supply, and the higher the jet from the aperture. If, instead of one layer of sand or gravel, there had been several, the reasoning would be the same, only it might happen that the upper layers had been closed up by the clay passing over them, as in the figure, and therefore be found unproductive of water, or that two layers of clay might come into contact with each other, and shut out the sand, both cases illustrated by recent borings at Portsmouth.

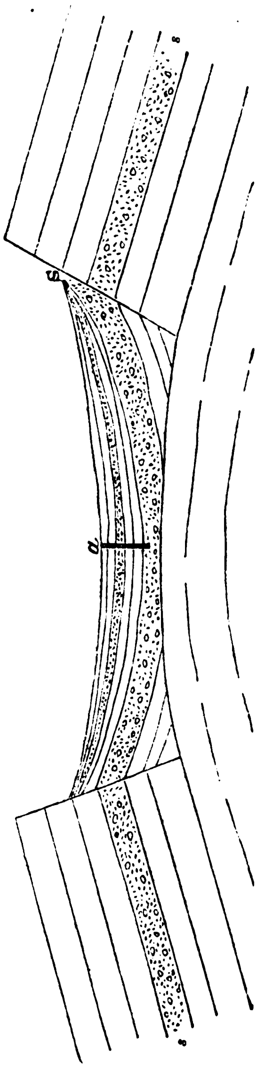
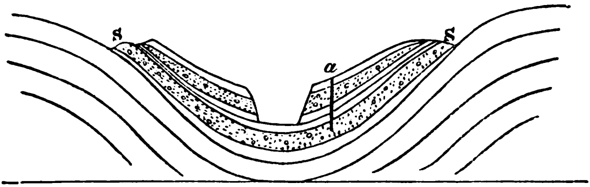


Fig. 23.

No. 23 is a basin formed within a valley of disruption or even of denudation, or which differs from the preceding only in this circumstance, that the boundary walls, as it were, of the valley may in themselves be partly pervious, and therefore allow the water to escape. If such occur, the water cannot rise above the level of these

discharging strata, represented in the figure. And again, secondary denudation may modify the basin deposit, and affect its supply of water, as in No. 24, where it is evident that any

Fig. 24.



layers of sand cut through by the denudation in the centre of the basin must discharge the water they receive at once into the inner valley of denudation, and that no water can be expected until the lower layer, or at least the first layer not affected by the denudation, has been touched by the borer. Faults may also materially affect the arrangement of springs, as in some cases when filled by impervious matter they may act as dams, and in others may discharge the water,—so that in boring in the vicinity of a fault, care must be taken to ascertain its condition, and if it be supposed open, to place the bore-hole in the strata dipping *from it*.

It is conceived that these examples are a guide sufficient in the application of principles to practice in every case, and will show the great necessity of studying the geological as well as the physical character of a country in which water is sought for. In granite, and in most crystalline rocks, such a search must be very precarious, as water can only be expected to occur in fissures. In stratified deposits, not metamorphosed, the occurrence of porous alternately with impervious beds brings the principle into operation; and in proportion as the porous beds are looser in texture, as in the tertiary and post-tertiary sands and gravel, and the arrangement of them is more limited by a basin-like form, so will the chance of success increase until it becomes a certainty. A correct knowledge of the stratification at the outcropping of

the strata must therefore be the surest guide. In boring, the strata passed through should be compared with those exhibited on the surface, in order to judge what specific stratum has been arrived at or passed through. Should there not be any of these basin-like deposits of looser materials, the pursuit of water in more solid strata must be equally guided by a knowledge of their geological and physical peculiarities; such, for example, as in the chalk and even in the oolite districts, as in such cases the numerous fissures may permit the water to descend, until it is stopped by either a less fractured bed or by some of the divisional clayey beds of such formations; and when once such bed or stratum has been discovered in any district, it becomes an index for the operations of the borer.

Although the several methods of boring cannot be here described in detail, it may be well briefly to notice the most remarkable.—1. The common one, in which an auger is used for soft soils, and chisels or jumpers for rocks. In this mode the boring tool is connected with the surface by jointed rods, fastened firmly together, and which must be frequently raised to clear the hole of the débris; so that in great depths the weight to be raised and the time lost in separating and refixing the joints become sources of great expense.—2. The Chinese mode, by percussion alone; the borer itself weighing about 180 lbs., and, being suspended by a cord, is alternately raised and allowed to fall, the débris either passing up through grooves in the sides of the tool and being then drawn up when accumulated on the head, or received into a separate cylinder with a valve opening from below upwards. This method is much more economical than the common, and has been used very extensively in Germany, though it is subject to two accidents requiring great precaution, viz. the great difficulty of drawing up a broken borer, and the danger, from the flexibility of the cord, of the bore-hole taking an oblique direction, and therefore requiring to be abandoned.—3. The system of Fauvelle, in which a hollow borer, either an auger or a

jumper, is used, the cutting tool being of larger diameter than the hollow stem, so that an annular space is formed around the borer; and water being forced down this space by a force-pump, ascends by the tube, bringing with it all the débris, or if forced down the tube, ascends in a similar manner by the annulus. This arrangement renders it unnecessary to bring up to the surface the boring tools, as they are constantly kept clear, and a vast saving of time and expense is the result.

In tracing out the sequence of strata which have now been passed under review, it is scarcely necessary to say that the Geologist will have had his hammer almost constantly in hand, and have found it often desirable to use some description of clynometer in unravelling the intricacies of stratification. Nor is it necessary to describe a peculiar form of hammer, as geological hammers can now be readily procured, and the form itself should be varied to suit the nature of the rock; or to figure any complex clynometer, as the observer may attain his object by very simple contrivances, such as a small wooden quadrant with a plumb-bob and a common pocket compass,—minute precision being unnecessary.

CHAPTER VIII.

Concluding Remarks.

It is hoped that the sketch which has been given in the preceding pages of a most interesting Science will have made its leading principles familiar to the reader's mind, but it may not be without advantage to recapitulate some of them, and at the same time to suggest that caution which is necessary both for their right perception and their correct application.

Sedimentary deposits must be studied in their mineral condition, in their organic fossils, and in the order of their stratification. The mineral condition is an indication of the physical circumstances which regulated the deposit, and must have so affected vegetable and animal life as to produce a peculiar local flora and fauna. As the physical condition of the earth's surface and the circumstances connected with it may have frequently varied in time and place, the mere mineral condition of a stratum is insufficient to determine the epoch of its deposition.

The organic fossils represent the flora and fauna of the epoch of deposition, but as the laws of organic development are not sufficiently known to enable the Naturalist to assume from *purely organic* considerations that any one generic or specific form must have preceded every other, the fossils alone are not sufficient to determine a geological epoch.

Order of stratification, as it embraces the examination both of the mineral and organic conditions of a deposit at its successive stages, or, in other words, of the physical and organic relations of the successive periods of deposition, is the only sure guide to the first determination of geological epochs. In

applying it, however, to this purpose care must be taken to avoid those sources of error which have been pointed out, by studying stratification in districts which have not been thrown into confusion by disturbing forces, as the contortions thus produced often place, to all appearance, the newer strata below the older, and sometimes invert a whole series of deposits. The relative ages of geological epochs being once established by the study of undisturbed districts, a clue is obtained by which the confusion of contorted strata may be reduced to order.

The natural progression of organic beings in space and time is represented by their lateral and vertical extension in geological strata: this progression has been sometimes violently interrupted by a sudden elevation or depression of the strata, the physical conditions required by such organisms having been thus as suddenly changed, which is well exemplified at the junction of *unconformable* formations: but this is not always the case, and in districts therefore which have not been disturbed at the interval between two successive formations, and in which the superior formation is *conformable* to the inferior, the interruption of organic progression is due either to a gradual alteration of physical condition as to depth, or to a change of climate, or to both combined. In the case of violently interrupted progression there will be an abrupt and marked change of zoological characters; in that of a gradual change of physical condition, an equally gradual change of zoological character; in the one a sudden alteration of formation, in the other a quiet transition. In the present state of natural operations, a gradual alteration appears to be the ordinary rule, and abrupt alterations, the local exception; and in like manner the labours of modern Geologists have done much to establish the same deduction for the former epochs of the Earth's History,—the establishment by Sir R. Murchison of a transition state between the chalk and the eocene formations being the most recent of these successful efforts.

The conditions of the earth which favour the continued existence of any specific organic form are now different in various

parts of its surface; nor can it be supposed, *à priori*, that at any epoch these conditions were perfectly uniform over the whole surface. And further, in the gradual progress of the earth to a state fitted for the reception of organic beings, it is reasonable to believe that some portions must have preceded others in thus becoming habitable, the progression taking place from the Poles to the Equator, which is rendered more probable by the greater development of the earlier fossiliferous formations in both high northern and southern latitudes. Where disturbances by elevation had begun to alter the physical conditions of the surface, and to modify the distribution of sea and land, the natural organic progression would be interrupted; but wherever such violent actions had not co-operated with the gradual change of temperature, it is reasonable to infer that the lateral and vertical extension of many organic bodies may have brought them into new positions on the earth's surface long after the conditions of the original centre of their creation had ceased to be such as to permit their continued existence, and thus to exhibit the characteristic organisms of one formation at the epoch of another: but here there will be usually found an explanation of the true state of the case in a mixture of characteristic forms of the new with those of the old formation. It is not therefore surprising that a carboniferous flora should appear in the Silurian, the Devonian, the carboniferous, and even more recent formations, although there can be little doubt that in each case careful observation will discover the new organic types which characterize the change of epoch.

This difficulty of always determining the actual simultaneity of apparently similar formations in no respect affects the practical application of Geology. In limited countries, such as Great Britain and Ireland, the physical conditions cannot have varied so unequally as materially to protract the existence of organisms in one place more than another; and hence the order of geological formation being once well established in one district, it becomes a certain guide to the examination of any

other. In more enlarged spaces, though synchronism of formation may not be established, the organic group which in one country was found to co-exist with some definite product being present, it may be assumed as at least probable that such product will have a similar co-existence in another.

Vast masses of strata which were once apparently stratified deposits have been so metamorphosed or changed that their original structure can no longer be recognized. Experiments in the laboratory have proved that similar changes can be effected on the small scale; and it is reasonable to conclude that the long continued and intense heat of the earth acting under pressure upon stratified deposits was sufficient to reduce them to the condition of the crystalline schists.

Rocks which had been in a state of igneous fusion can be traced from the earliest epochs, and they are found to graduate into the true volcanic rocks of the present time. The effects they have produced on some of the strata frequently determine the epoch of their appearance, but there is often much difficulty in determining the relative ages of such rocks, and still more the depths from which they have proceeded. It has been here suggested that specific gravity may possibly afford the safest method of solving such questions, and in conformity with it, that granite has probably proceeded from a less depth than most of the porphyries and basalts.

The penetration of strata, in the form of dykes, by igneous rocks, the contortions of the strata, and the elevation of mountain chains, are so many proofs of the operation at various epochs of disturbing forces, the nature of which is still testified by volcano and earthquake. If the primary cause of such disturbances be the pressure of the solidifying and contracting crust upon the still liquid nucleus of the earth, it is reasonable to believe that the intensity of the elevating force should increase with the augmenting thickness and pressure of the contracting crust, though the quantity of matter erupted may decrease; nor is this inconsistent with facts, as the great mountain chains have been elevated at comparatively recent

epochs, whilst the ancient basaltic flows appear to have been, as a whole, more extensive than those of recent volcanoes. In respect to contortions, they may be either explained as the result of pressure on the solidifying strata by the wave-like movement of the disturbed fluid matter, or be considered, according to the theory of Professor Rogers, to represent the wave itself continued into the crust. To Professor Rogers is due the most laborious and accurate examination of the facts of contortions, and a most perspicuous enunciation of his theory founded upon them, but it may yet be doubted whether a simple wave of translation of a dense liquid mass can be made to conform to the varied forms of contortion. Whilst, then, such swells of the comparatively level surface as have been demonstrated by the pendulum deductions of M. Rozet may be reasonably considered waves corresponding to those of the liquid nucleus, contortions are probably the effect of pressure on strata which are not sufficiently elastic to follow the movement of the liquid wave, and are in consequence folded together.

In studying many natural phenomena, such for example as denudation, the apparent magnitude of a result should not be allowed to oppress or perplex the mind, as it must be remembered, that though almost immeasurably vast in the limited perceptions of man, they are atomic when compared to the magnitude of the earth itself; but it is by no means philosophical to apply such a rule to the estimation of forces in the explanation either of wear or of contortions. The laws of matter are uniform and general, as the force of gravity may be studied as well in the fall of a pebble as in that of a mountain, and the magnetic force of the earth in the vibrations of a needle. The phenomena stand forth as facts to be observed and studied; but in seeking to explain them, no supposition of unknown forces, immense in proportion to the forces we see acting on the earth, just as that earth itself is to the mountain which studs or the valley which dimples its surface, can be admitted. The density of the earth, and the

laws which regulate its motion, are known, and the general properties of matter, whether at rest or in motion, are also known; and it cannot therefore be said that the elements are wanting for the full elucidation of all physical phenomena, or that any theory is fully established which cannot be shown to conform to known physical laws.

THE END.

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